Westinghouse

LIGHTING HANDBOOK

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WESTINGHOUSE ELECTRIC CORPORATION

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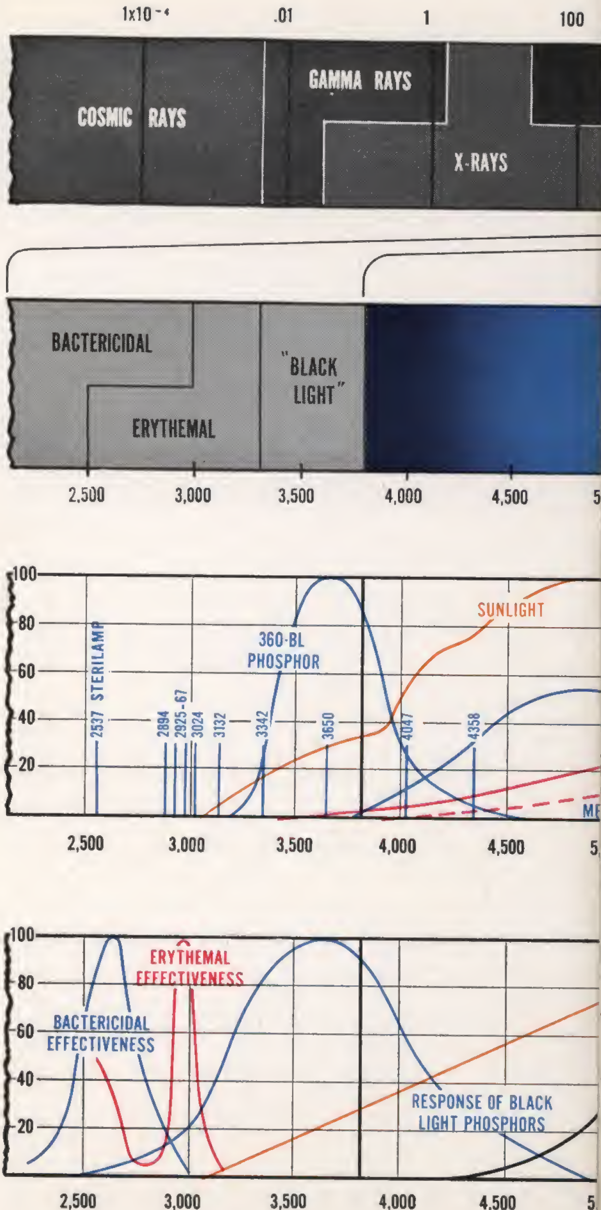

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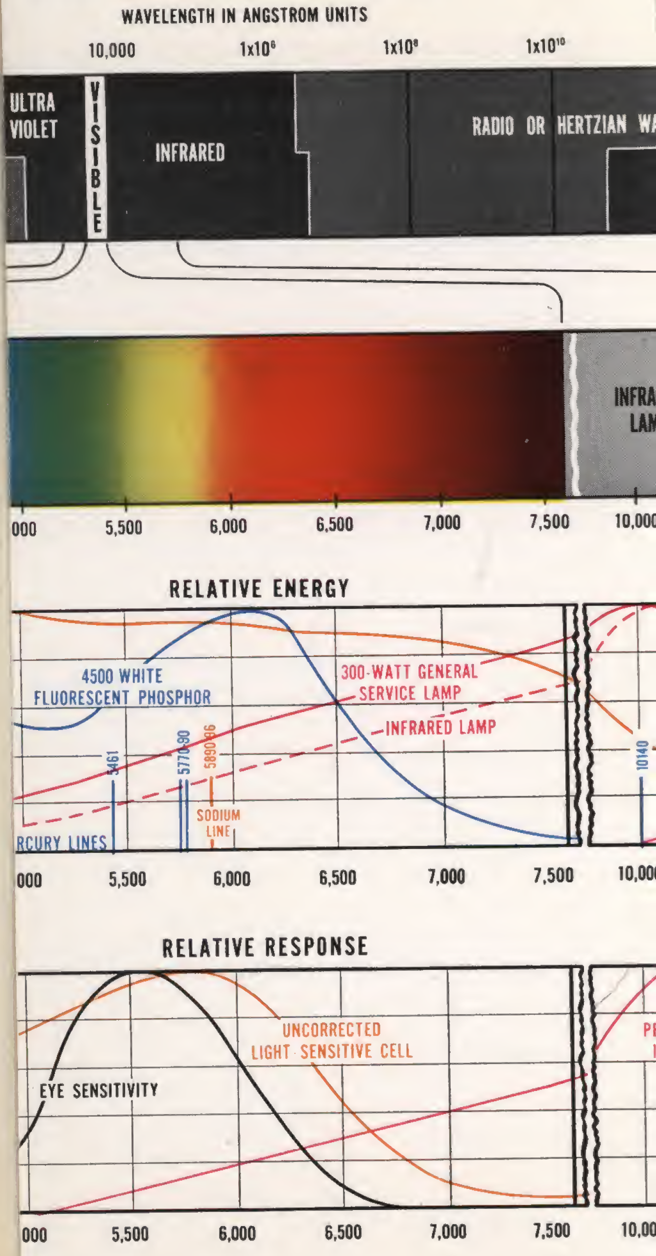
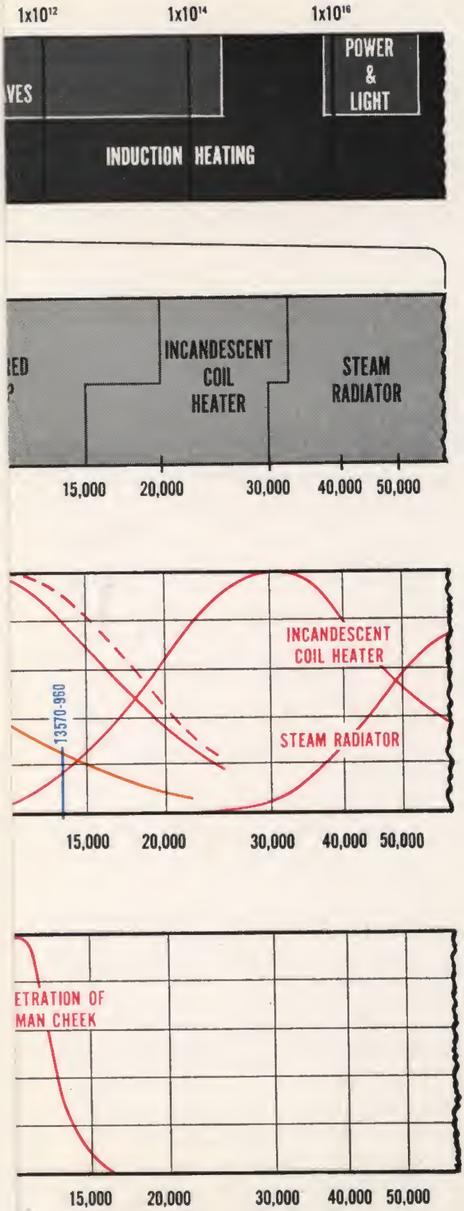
ELECTROMAGNETIC SPECTRUM

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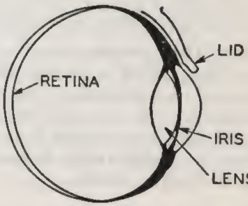
CHAPTER ONE

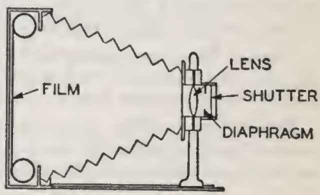
THE EYE AND VISION

Since the purpose of lighting is to make vision possible, any study of lighting must begin with a consideration of the eye and the seeing process. Only as the illuminating engineer understands the mechanism of the eye and the way in which it operates can he satisfactorily fulfill his primary function—to provide light for the performance of visual tasks with a maximum of speed, accuracy, ease, and comfort, and a minimum of strain and fatigue.

THE SEEING MECHANISM



The human eye is often compared to the camera, which in many respects it resembles. Each has a *lens*, which focuses an inverted image on a light-sensitive surface—the *film* in a camera, the *retina* in the eye. The *eyelid* corresponds to the camera *shutter*. In front of the lens in the camera is a *diaphragm*, which may be opened or closed to regulate the amount of light entering the camera. In front of the lens in the eye is the *iris*, which performs the same function.

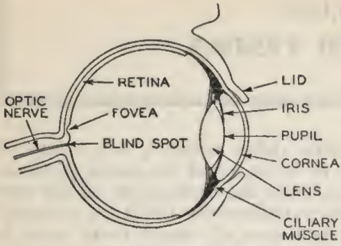


However, this analogy cannot safely be carried too far. There are important differences between the eye and the camera. The eye is a living organ and it is amazingly adaptable, operating over a range of illumination levels greater than a million to one. Furthermore, the continuous changes necessary for good vision under constantly changing conditions are made automatically, without conscious effort. Because of these facts, it is quite possible to abuse the eye. Taking pictures in dim light or in poor focus does no harm to the camera. But using the eyes under light of insufficient quantity or poor quality results, at least, in excessive consumption of nervous energy and unnecessary fatigue, and may lead to inflammation of the eyes and headaches. Consistent misuse of the eyes may even be a contributing cause in the development of disorders in other parts of the body.

THE PARTS OF THE EYE AND THEIR FUNCTIONS

Eyelid—A flap of skin that protects the eye, and under conditions of extremely high brightness helps to regulate the amount of light reaching it.

Cornea—A transparent portion of the outer membrane surrounding the eye. It serves as part of the refractive system.



Iris—The colored (blue, brown) portion of the eye, which functions as a diaphragm, controlling the amount of light entering the eye.

Pupil—The opening in the center of the iris through which light enters the eye. The size of the pupil opening is controlled by the action of involuntary muscles.

Lens—A transparent capsule behind the iris whose shape can be changed in order to focus objects at various distances.

Ciliary Muscle—A ring-shaped muscle which adjusts the tension on the lens, thereby changing its curvature to focus near or distant objects.

Retina—The light-sensitive surface at the back of the eyeball. It contains a delicate film of nerve fibers branching out from the *optic nerve*, and ending in minute cone- and rod-shaped structures.

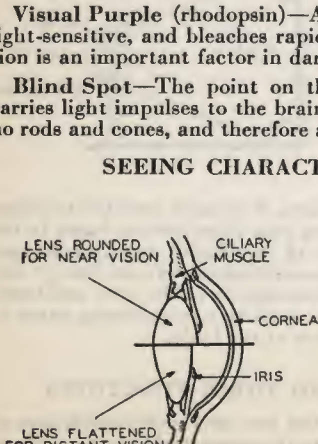
Cones—The receptors in the retina which make possible the discrimination of fine detail and the perception of color. They are insensitive at low levels of illumination. The cones are found principally near the center of the retina, with the greatest concentration at the *fovea*, an area about 0.3 mm in diameter which is composed of cones alone. It is at the fovea that the eye involuntarily focuses the image of an object that must be examined in minute detail.

Rods—The receptors in the retina which are sensitive to low levels of illumination. They have no color response. Rods are found only outside the foveal region, increasing in number with distance from the fovea. The outer portions of the retina, composed chiefly of rods, do not afford distinct vision, but are highly sensitive to movement and flicker.

Visual Purple (rhodopsin)—A purple liquid found in the rods. It is light-sensitive, and bleaches rapidly when exposed to light. Its regeneration is an important factor in dark adaptation.

Blind Spot—The point on the retina where the optic nerve, which carries light impulses to the brain, enters the eye. At this point there are no rods and cones, and therefore a light stimulus gives rise to no sensation.

SEEING CHARACTERISTICS OF THE EYE



Accommodation—When the lens is at its flattest, the normal eye is focused on objects at infinity. To focus on nearer objects, particularly within 20 feet, necessitates increasing the convexity of the lens by the contraction of the ciliary muscle. The nearer the object, the more convex the lens must become. This is part of the process known as *accommodation.*

Accommodation also includes changes in pupil diameter. When the eye is focused on distant objects

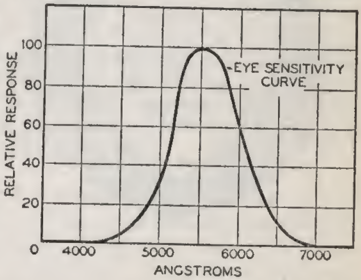
the pupil is relatively large. When attention shifts to a close visual task the pupil contracts somewhat, achieving sharper definition but admitting less light to the eye.

Adaptation—The eye is enabled to function over a tremendously wide range of illumination levels by means of a process known as *adaptation.* Adaptation involves a change in the size of the pupillary opening, along with photochemical changes in the retina.

The size of the pupil opening is primarily a function of the amount of light received at the eye. In very dim light the pupil opens wide, but with higher illumination the opening becomes smaller. This is particularly apparent on going from a well-lighted area to a much darker one, or when a glaring light source comes within the range of vision. The retinal change involves a balancing of the rate of regeneration of the photochemical substances in the retina against the requirements of the eye for a given situation.

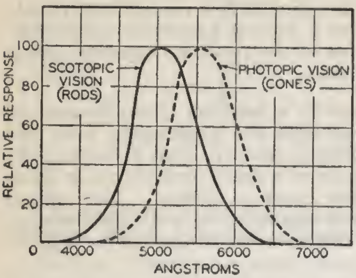
The length of time required for the adaptation process depends upon the previous state of adaptation and the magnitude of the change. In general, however, adaptation to a higher illumination level takes place more rapidly than in the opposite direction. The major share of light adaptation ordinarily occurs during the first minute, whereas adaptation to darkness proceeds quite rapidly for fully 30 minutes, and complete dark adaptation may require an hour. These are facts which the illuminating engineer must consider in lighting motion picture theaters, traffic tunnels, or any areas where people pass abruptly from one lighting level to another.

Eye Sensitivity Curve—The eye is not equally sensitive to energy of all wavelengths, i.e., to all colors. Tests on a large number of observers have established an *eye sensitivity curve* which gives the response of the average eye to equal amounts of energy at the various wavelengths of light. The maximum sensitivity is in the yellow green, at a wavelength of about 5550 Angstroms, and the sensitivity at the blue and red ends of the spectrum is very low by comparison. This means that approximately 9 units of red energy at a wavelength of 6500 Angstroms are needed to produce the same visual effect, or brightness, as one unit of yellow green. It is obvious that the eye sensitivity curve must always be taken into account in evaluating visible energy in terms of sensation.

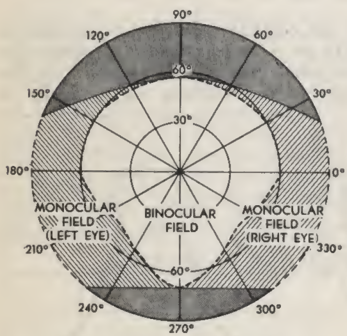


In the practical application of lighting for seeing, strong spectral colors are never employed, and tests indicate no appreciable advantage for ordinary visual tasks in the use of sodium or mercury vapor lamps, or other colored light sources. The psychological effect of color, however, may be more pronounced with some individuals than with others, and designers must sometimes regard personal color preferences in selecting light sources, even though no difference in seeing ability can be expected to result.

Purkinje Effect—The standard (*photopic*) eye sensitivity curve is based on "cone vision"—that is, ordinary daylight levels of illumination in which the cones are the visual mechanism involved. At very low levels of illumination, where the brightnesses are of the order of 0.001 footlambert or less, the cones no longer function, and the rods take over the entire seeing process. In rod, or *scotopic*, vision a new sensitivity curve becomes effective, of the same shape as the photopic curve, but displaced 480 Angstroms toward the blue end of the spectrum. This shift, which is known as the *Purkinje effect*, places the maximum sensitivity of the eye at 5070 rather than at 5550 Angstroms.



The result is that in dim light, although vision is entirely colorless, the eye becomes relatively very sensitive to energy at the blue end of the spectrum, and almost blind to red. Thus if a beam of red light and a beam of blue light, of equal intensity at photopic levels, are reduced in the same ratio to the region of scotopic vision, the blue light will appear very much brighter than the red. The implications of the Purkinje effect are important in lighting installations involving very low illumination levels, and failure to recognize them may lead to serious errors in the measurement of low brightness and candlepower values.



Visual Field—The normal *visual field* extends approximately 180° in the horizontal plane and 130° in the vertical plane, 60° above the horizontal and 70° below. The *fovea*, where most seeing and all discrimination of fine details are done, subtends an angle of less than one degree at the center. The limits of what may be called the *central field*—the visual task and its background—vary with the task. The *surroundings* are usually considered as extending from the outer limit of the central field to a circle approximately 30° from the optical axis. At 30°, visual acuity is only about one per cent of its value at the fovea. Vision is very indistinct in the outer portions of the field beyond this angle, although changes in brightness or movement can be readily detected.

Structural Eye Defects—The four most common causes of defective vision are:

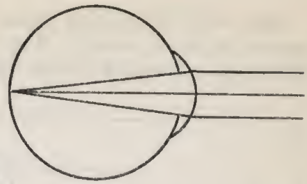
Astigmatism (the inability to bring horizontal lines and vertical lines into focus at the same time). The focal length of the astigmatic eye is different in two planes at right angles to one another. This condition results from irregularities in the curvature of the cornea and the lens.

Myopia (nearsightedness). The focal length of the myopic eye is too short, and parallel light rays focus *in front of* the retina, rather than sharply on it. The nearsighted person sees near objects clearly, but distant ones appear blurred.

Hypermetropia (farsightedness). Here the focal length of the eye is too great, and the focal point for parallel rays is *behind* the retina. The farsighted person cannot see close objects clearly.

Presbyopia (loss of accommodating power of the lens). In middle and old age the lens becomes progressively less elastic, and the process of accommodation for near vision is more and more difficult. The result is a condition similar to farsightedness.

All four of these visual defects can usually be corrected by properly fitted glasses.



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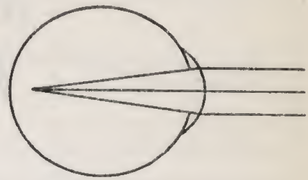
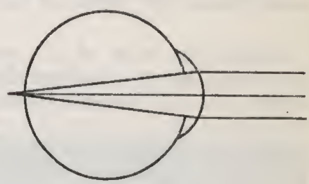


NEARSIGHTED



FARSIGHTED

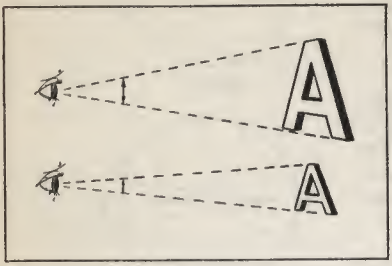
Flicker—The eye does not respond instantly to a light stimulus, nor does the sensation of vision cease immediately when the stimulus is removed. When the eye is exposed to a source of rapidly varying intensity this *persistence of vision* may keep the flicker from being detected, as is the case in motion picture observation. All light sources operated on alternating current exhibit some degree of cyclic variation in light output. Ordinarily the variation is so rapid and so slight that normal persistence of vision prevents any sensation of flicker. In incandescent lamps it is seldom noticeable except on 25-cycle service.

Mercury vapor lamps and fluorescent lamps operated on 60-cycle service may, if not properly corrected, produce a flicker which causes the observer to see multiple images of any moving object. This phenomenon, known as *stroboscopic effect*, and the means of minimizing it are further discussed in Chapter Three.

OBJECTIVE FACTORS IN THE SEEING PROCESS

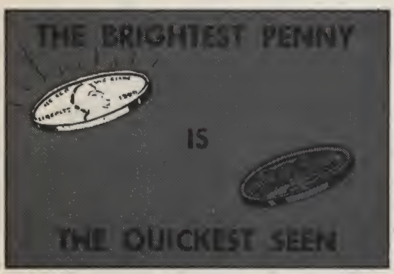
Investigation has shown that seeing depends upon four primary variables associated with the visual object: its size, its brightness, the brightness contrast between it and its immediate background, and the time available for seeing it.

Size—The *size* of the object is the most generally recognized and accepted factor in seeing. The larger an object in terms of *visual angle* (the angle subtended by the object at the eye) the more readily it can be seen. The familiar eye test chart illustrates this principle. The person who brings a small object close to his eye in order to see it more clearly is unconsciously making use of the size factor by increasing the visual angle.

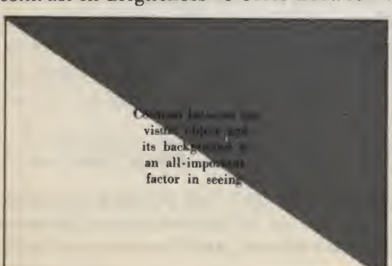


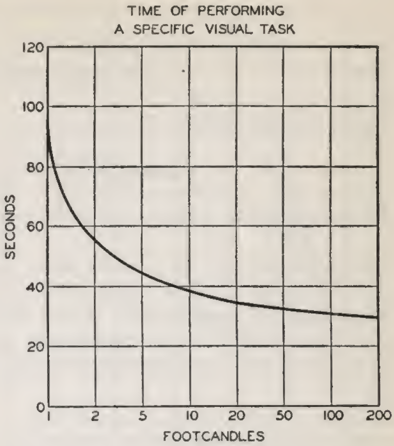
Visual acuity, expressed as the reciprocal of the visual angle in minutes, is a measure of the smallest detail that can be seen. Since visual acuity increases markedly with increase in illumination, light is sometimes said to act as a "magnifier," making visible small details that could not be seen with less light.

Brightness—One of the primary factors in visibility is *brightness*. The brightness of an object depends both upon the intensity of the light striking it, and the proportion of that light reflected in the direction of the eye. A white surface will have a much higher brightness than a black surface receiving the same illumination. However, by adding enough light to a dark surface it is possible to make it as bright as a white one. The darker an object or a visual task, the greater the illumination necessary for equal brightness and, under like circumstances, for equal visibility.



Contrast—As important for seeing as general brightness-level is the *contrast* in brightness or color between the visual object and its immediate background. The difference in the visual effort required to read the two halves of the chart at the left is a simple demonstration of the effectiveness of contrast. High levels of illumination partly compensate for low brightness contrasts, and are of great assistance where poor contrast conditions cannot be avoided.





Time—Seeing is not an instantaneous process; it requires *time*. Here again the camera may be used for illustration: A picture can be taken in very dim light if the exposure is long enough, but for a fast exposure a great deal of light is necessary. The eye can see very small details under low levels of illumination, if sufficient time is allowed and eyestrain is ignored. But more light is required for *quick* seeing.

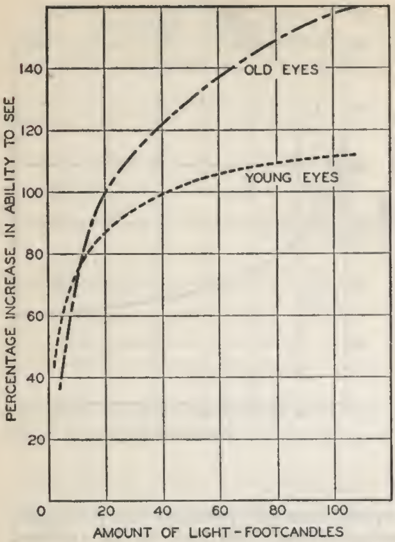
The accompanying curve illustrates the way in which the speed of performance of a specific visual task increases with increased illumination. Since human muscular activity has a definite limit, it is logical to find the curve leveling off as that limit is approached. However, the attainment of maximum speed does not preclude the possibility that the benefits of greater illumination may continue to be realized, beyond that point, in the form of less nervous energy required to perform the task.

The time factor is particularly important where the visual object is *in motion*. High lighting levels actually make moving objects appear to move more slowly, and greatly increase their visibility.

Size, *brightness*, *contrast*, and *time* are mutually interrelated and interdependent. Within limits a deficiency in one can be made up by an adjustment in one or more of the others. In most cases, size is a fixed factor of the visual task, with brightness, contrast, and time subject to some degree of modification. Of these, brightness and contrast are usually most directly under the control of the illuminating engineer. Properly employed, they can be of tremendous aid in overcoming unfavorable conditions of small size and limited time for seeing.

SUMMARY

The human eye has evolved through countless ages when it was used almost entirely out of doors, in bright daylight, and for simple, long-range seeing. Today man lives and works largely indoors, and uses his eyes, too often under entirely inadequate artificial illumination, for long hours at close tasks involving constant accommodation. Statistical studies of various occupational groups indicate a definite correlation between the visual demands of the work and the percentage of workers with defective vision. College students, draftsmen, and bookkeepers, for example, show a much higher incidence of eye defects than farmers and sailors. Good lighting can do much to improve the conditions under which



eyes must work, and to relieve the eyestrain involved in the performance of difficult visual tasks. Research reveals that the advantages of high illumination levels are even more apparent with old eyes and defective eyes than with young, normal, eyes.

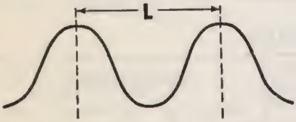
Only the simple, basic principles of the operation of the eye and the seeing process have been enumerated in this chapter. Most visual tasks are highly complex, involving not only these fundamental factors but many others, all of them interrelated. The situation is further complicated by physiological and psychological factors which condition the observer's response to any light stimulus, and which vary, not only from one individual to another, but for the same individual at different times.

CHAPTER TWO
LIGHT—CHARACTERISTICS AND MEASUREMENTS

THE RADIATION SPECTRUM

Light is that form of radiant energy which is capable of producing the sensation of sight.

Visible energy is an exceedingly small portion of the *electromagnetic spectrum*, a tremendous range of radiant energy which travels through space in the form of electromagnetic waves. All of these radiations are similar in nature and in the speed at which they travel (186,300 miles per second). They differ only in wavelength and frequency, and in the ways



The distance between crests of successive waves, shown here as L, is wavelength. Since wavelength times frequency equals velocity, which is constant, frequency is inversely proportional to wavelength.

in which they manifest themselves. The present known spectrum ranges from cosmic rays with a wavelength of 1×10^{-15} cm, and a frequency of 3×10^{25} cycles per second, to 60-cycle alternating-current waves 3100 miles long. The human eye is tuned to respond only to the energy within the limits of the *visible spectrum*, a narrow band of wavelengths between 3800 Angstroms and 7600 Angstroms. (The Angstrom* is a wavelength unit equal to one ten-millionth of a millimeter, or approximately four-billionths of an inch.) Energy in this region, evaluated in terms of the eye sensitivity curve (see Chapter One), is *light.*

Color

The *color* of light is determined by its wavelength. Light at the short-wave end of the visible spectrum, from 3800 to about 4500 Angstroms, produces the sensation of violet; the longest visible waves, from about 6400 to 7600 Angstroms, appear as red. Between these limits lie the wavelengths which the eye distinguishes as blue (4500-4900 Angstroms), green (4900–5600), yellow (5600–5900), and orange (5900–6400)—the colors of the rainbow.

The spectrum of a light source may be *continuous*, including all the visible wavelengths, or it may be a *line* or a *band* spectrum, containing only one or a few separated groups of wavelengths. A tungsten filament has a continuous spectrum, a mercury arc a line spectrum. An *equal-energy* spectrum—that is, all the visible wavelengths in equal quantities—produces the sensation of white light. Noon sunlight approximates an equal-energy spectrum.

* The *micron*, equal to one-millionth of a meter, is another unit often used to express wavelength. One micron is 1×10^4 Angstroms.

Color Temperature

Color temperature is a term sometimes used to describe the color of the light from a source by comparing it with the color of a *blackbody*, a theoretical "complete radiator" which absorbs all radiation that falls on it, and in turn radiates a maximum amount of energy in all parts of the spectrum. A blackbody, like any other incandescent body, changes color as its temperature is raised. The light from a White fluorescent lamp is similar in color to the light from a blackbody at a temperature of approximately 3500° Kelvin*, and the lamp is accordingly said to have a color temperature of 3500°K. The light from a Daylight fluorescent lamp is bluer, and the blackbody must be raised to 6500°K to match it. Hence the Daylight lamp has a color temperature of 6500°K.

Color temperature is not a measure of the *actual temperature* of an object. It defines *color only*. Some light sources, such as a sodium vapor lamp, or a Green or Pink fluorescent lamp, will not match the color of a blackbody at any temperature, and therefore no color temperatures can be assigned to them.

* Kelvin is a temperature scale which has its zero point at −273° Centigrade.

TERMINOLOGY AND MEASUREMENTS

QUANTITY	SYMBOL	UNIT	DEFINITION
Luminous Intensity (Candlepower) Light density in a specified direction.	I	Candle (c) The luminous intensity of a source expressed in candles is its Candlepower (cp)	The standard unit of luminous intensity in a given direction is the *International Candle.* An ordinary wax candle has a luminous intensity in a horizontal direction of approximately one candle. The International Candle is the basic quantity in all measurements of light. Candlepower is always a property of a source of light, and gives information regarding luminous flux at its origin.
Luminous Flux Time rate of flow of light. Light is actually a form of radiant energy in motion. In common practice, however, the time element is neglected, and luminous flux is considered as a definite quantity.	F	Lumen (lm)	A lumen is the light flux falling on a surface one square foot in area, every point on which is one foot from a uniform point source of one candle. (Such a surface is a one-foot-square section of a sphere of one-foot radius, with a one-candle source at its center.) The lumen differs from the candle in that it is a measure of light flux *irrespective of direction.*

Light travels in straight lines, unless it is modified or re-directed by means of a reflecting, refracting, or diffusing medium.

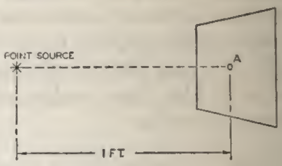
Light waves pass through one another without alteration of either —for example, a beam of red light will pass directly through a beam of blue light unchanged in direction or color.

Light is invisible in passing through space unless some medium (such as dust) scatters it in the direction of the eye.

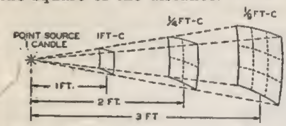
COLOR TEMPERATURES
Degrees Kelvin
(Approximate Values)

Blue Sky	10,000 to 30,000
Overcast Sky	7000
Daylight Fluorescent Lamp	6500
Noon Sunlight	5250
500-Watt Daylight Incandescent Lamp	4000
White Fluorescent Lamp	3500
Photoflood Lamp	3415
General Service Incandescent Lamps	2500 to 3050
Candle Flame	1800

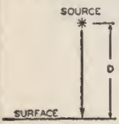
FUNDAMENTAL EQUATIONS	METHOD OF MEASUREMENT	PRINCIPAL USE
CP = Footcandles x D^2 (D = Distance in feet from source to illuminated surface) See Illumination. $\text{MSCP} = \frac{\text{Lumens}}{12.57}$ (Mean spherical candlepower is the average candlepower of a source in all directions.)	Candlepower measurements are primarily a laboratory procedure requiring special instruments. Rough estimates of the candlepower of a source or fixture can be made in the field by (1) holding a light meter at a distance of at least five times the greatest dimension of the source; (2) aiming the cell of the meter directly at the source; and (3) multiplying the footcandle reading by the square of the distance in feet. (See Fundamental Equations.) There must of course be no other light in the room, and it may be necessary to make allowance for light reflected from walls and ceilings.	Candlepower is used not only to indicate the luminous intensity of a source in one particular direction; candlepower measurements are often taken at various angles around a source or a fixture, and the results plotted to give a *candlepower distribution curve.* Such a curve shows luminous intensity in any direction, and from it illumination calculations can be made. (See section on Distribution Curves, and Chapter Six, Point-By-Point Method.)
Lumens incident on a surface = Footcandles x Area (sq. ft.) Lumens emitted or reflected by a surface = Footlamberts x Area (sq. ft.) Lumens = MSCP x 12.57 (Since a sphere of one-foot radius has a surface area of 4π (12.57) square feet, a uniform point source of one candle must produce 12.57 lumens. The same relationship exists between the mean spherical candlepower of any source and its total lumen output.)	Lumen measurements of light sources are a laboratory procedure requiring special equipment. The lumens falling upon a surface may, however, be estimated with the aid of an ordinary light meter. First obtain footcandle readings at various points on the surface in order to arrive at an average value; then multiply the average footcandles by the area of the surface in square feet. (See Fundamental Equations.)	The lumen is used primarily to express the total output of a light source. It can also be used to indicate amount of light absorbed, transmitted, or reflected. The Lumen Method (see Chapter Six) of calculating illumination provides average footcandle values by the use of relatively simple formulas.

QUANTITY	SYMBOL	UNIT	DEFINITION
Illumination Density of luminous flux on a surface. Luminous flux may be called the *cause*, and illumination the *effect* or result.	E	Footcandle (ft-c)	A footcandle is the illumination at a point (A) on a surface which is one foot from and perpendicular to a uniform point source of one candle.  From the definition of a lumen it is obvious that one lumen uniformly distributed over one square foot of surface produces an illumination of one footcandle.
Brightness Luminous intensity in a given direction per unit of (projected) area. A surface or an object has *brightness* by reason of light emitted, reflected, or transmitted. Brightness is ordinarily independent of distance of observation.	B or B^1	Candle per square inch ($c/in.^2$) or Footlambert (ft-L)	Brightness is expressed in two ways: in *candles* per unit area, or in *lumens* per unit area. A surface emitting or reflecting light in a given direction at the rate of one candle per square inch of projected area has a brightness in that direction of *one candle per square inch*. A surface which has a brightness equal to the uniform brightness of a perfectly diffusing surface emitting or reflecting one lumen per square foot has a brightness of *one footlambert*. The footlambert is also the average brightness of any surface emitting or reflecting light at the rate of one lumen per square foot. A *lambert* is the brightness of a surface emitting or reflecting one lumen per square centimeter; a *millilambert* is one-thousandth of a lambert.

<table>
<tr><th>FUNDAMENTAL EQUATIONS</th><th>METHOD OF MEASUREMENT</th><th>PRINCIPAL USE</th></tr>
<tr>
<td>
Inverse Square Law
Illumination decreases inversely as the square of the distance.



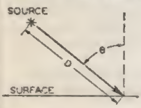
When light rays are perpendicular to the surface, the inverse square law as stated above applies:



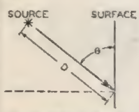
$$E = \frac{I}{D^2}$$

E = Footcandles
I = Candlepower
D = Distance in feet

When light rays are not perpendicular to the surface:



$$E_h = \frac{I \times \text{Cosine } \theta}{D^2}$$



$$E_v = \frac{I \times \text{Sine } \theta}{D^2}$$

Footcandles incident on a surface = $\frac{\text{Lumens}}{\text{Area (sq. ft.)}}$
</td>
<td>Various models of direct-reading light-sensitive cell footcandle meters and visual photometers are available. A discussion of these instruments and their use is found in the following section entitled Field Measurements.</td>
<td>Footcandle readings are used to indicate the illumination at a specific point, or the average illumination on a surface. The inverse square law is the basis of calculation in the Point-By-Point Method of lighting design.

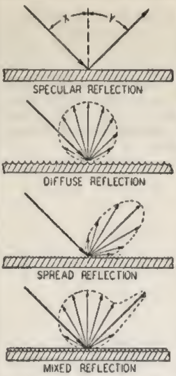
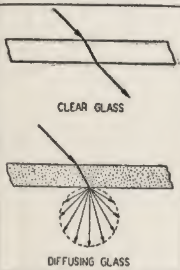
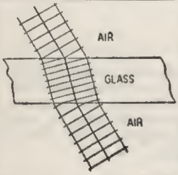
The inverse square law applies strictly only to a point source. With most types of interior lighting fixtures, however, it is safe to assume that the law operates with sufficient accuracy for all practical purposes if the distance at which the measurements are taken is at least five times the greatest dimension of the light source. For special considerations involving linear sources and parallel beams of light, see Chapter Six.</td>
</tr>
<tr>
<td>
Ft-L = Footcandles x Reflection factor of surface

$$\text{Ft-L} = \frac{\text{Lumens (incident)} \times \text{Reflection factor}}{\text{Area (sq. ft.) of surface}}$$

1 Candle per sq. in. = 452 Footlamberts

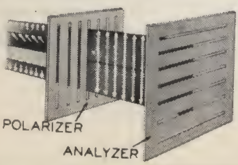
If the surface under consideration departs widely from the properties of a perfect diffuser, the lumens emitted or reflected cannot safely be calculated on the basis of a single brightness reading taken from any one angle.

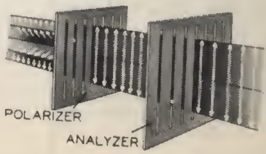
1 Lambert = 929 Footlamberts
= 2.054 Candles per sq.in.
1 Millilambert = 0.929 Footlamberts
= 0.002 Candles per sq. in.
</td>
<td>Methods of making brightness measurements and the meters used for the purpose are described later in this Chapter under Field Measurements.</td>
<td>Relatively high brightnesses, such as those of light sources, are usually expressed in terms of candles per square inch. Since the average brightness of a surface in footlamberts can be calculated by multiplying the illumination in footcandles by the reflection factor (see Fundamental Equations), the footlambert is a very convenient unit in which to express the brightnesses of illuminated surfaces.</td>
</tr>
</table>

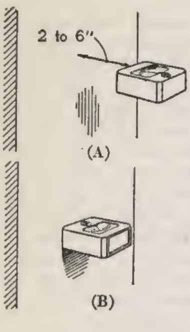
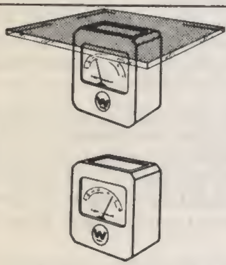
TYPE OF CONTROL	ILLUSTRATION	UNIT	METHOD OF MEASUREMENT
Reflection When a ray of light striking a surface is turned back, it is said to be *reflected.* Reflection may be of several types, the most common of which are *specular* (regular), *diffuse, spread,* and *mixed.*		**Reflection Factor** The ratio of the light reflected from a surface to that incident upon it. The reflection factor of a given surface may vary considerably according to the direction and nature of the incident light. Specular reflection increases with angle of incidence, almost total reflection being obtainable at grazing angles. With colored surfaces the reflection factor may be quite different for different colors of light.	Place light meter cell against surface. Withdraw meter from surface slowly until constant reading is obtained (2 to 6 inches). (A) Place meter against surface with cell facing out (B) and note reading. Reflection factor = $\frac{\text{Reading (A)}}{\text{Reading (B)}}$
Transmission Light rays passing through transparent or translucent materials are said to be *transmitted.* The degree of diffusion of the transmitted light depends upon the type and density of the material.		**Transmission Factor** The ratio of the light transmitted by a material to that incident upon it. Transmission depends to some extent upon the direction and quality of the light.	Place material to be tested over cell of light meter. Note reading (A). Remove material. Note reading (B). Transmission factor $= \frac{\text{Reading (A)}}{\text{Reading (B)}}$
Refraction A light ray bent by passing obliquely from one transparent medium to another in which its velocity is different (as from air into glass) is said to be *refracted.*		**Index of Refraction** The ratio of the speed of light in free space to the speed of light in the medium in question.	By special laboratory apparatus only.

Polarization

Light in which the waves vibrate in one plane only is said to be *polarized.* The vibrations which make the wave motion in a ray of light are at right angles to the direction in which the light is traveling, and in a beam of ordinary light these vibrations take place in all possible directions in that plane. By passing light through a material with a crystalline structure such that it transmits only waves vibrating in a certain direction, it is possible to produce polarized light, all of whose vibrations are parallel.



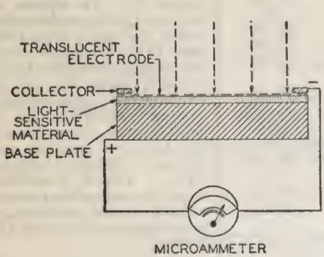


INSTRUMENT	MATERIALS	USE
	Reflecting Surface — Per Cent Light Reflected Magnesium Carbonate....97–98 Polished Silver.... 90 White Plaster....85–90 Mirrored Glass....80–90 Alzak Aluminum....80–85 White Blotting Paper....80–85 Porcelain Enamel...77–82 White Paint....75–85 Polished Chromium. 65 Polished Aluminum.60–70 Polished Nickel.... 65 Aluminum Paint....50–75 Black Paint.... 3–5	In *specular*, or *regular*, reflection (mirrors, highly polished metals) the angle of incidence is equal to the angle of reflection (see Illustration: Angle X = Angle Y). In *diffuse* reflection (matte surfaces like white blotting paper, fresh snow) the maximum intensity is perpendicular to the surface, regardless of the angle of the incident beam. *Spread* reflection, as in sanded glass, is intermediate between specular and diffuse. Diffusing surfaces with a glazed superficial coat, like porcelain enamel, exhibit *mixed* reflection, a combination of specular and diffuse.
	Type of Glass — Per Cent Light Transmitted Clear....80–90 Frosted....75–85 Figured or Ribbed Crystal....70–85 Light-Density Diffusing....55–70 Heavy-Density Diffusing....10–45	In *regular* transmission (clear glass and plastics) the direction of the incident light is not changed. Diffusing media, such as dense opal glass, scatter the transmitted light so that its maximum intensity is normal to the surface. As in reflection, between the two extremes of regular transmission and perfectly diffuse transmission are to be found all degrees of diffusion.
	Index of Refraction for Various Materials Water....1.33 Alcohol....1.36 Turpentine....1.47 Crown Glass....1.53 Flint Glass....1.67 Diamond....2.47	The principle of *refraction* is utilized to control the direction of light by means of prismatic or ribbed glass plates, or in lens systems. It has wide application in certain types of general lighting systems, as well as in signal lighting and street lighting.
Two polarizing screens are ordinarily used in a system that involves polarization. The first, called the *polarizer*, produces the polarization, and the second, called the *analyzer*, selects or rejects the polarized light, according to the position in which it is placed.	Crystals of Iceland spar, calcite, and tourmaline; Polaroid, (a cellophane-like material available commercially). Reflection from specular or polished surfaces partially polarizes light.	The principle of *polarization* is used in certain kinds of laboratory equipment, and in testing for stress and strain in transparent materials; in producing third-dimension effects in motion pictures; in sun glasses and automobile visors to reduce reflected glare from road surfaces and water; in photographic filters. Experimental work on the control of automobile headlight glare by means of polarizing material is under way.

FIELD MEASUREMENTS

Footcandle Measurements

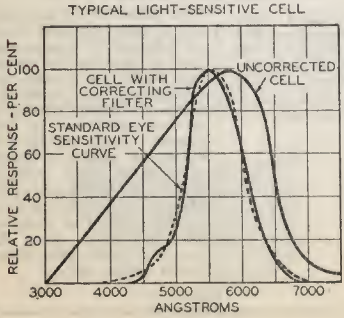
Illumination measurements are most commonly made with one of the several types of footcandle meters embodying light-sensitive barrier-layer cells. This type of cell consists essentially of a film of light-sensitive material mounted on a metal base plate and covered by a very thin translucent layer of metal sputtered on its outer surface. Light striking the cell surface causes the semi-conducting light-sensitive material to emit electrons, which are picked up by a metal collector in contact with the translucent front electrode. A potential difference is thus set up between the collector and the base plate, and when a microammeter is connected between them it measures the current generated by the cell. Since the current is proportional to the intensity of the incident light, the meter can be calibrated to read directly in footcandles. In some instruments the meter is enclosed in the same case with the cell, in others merely connected to it electrically.



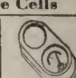
Although light-sensitive-cell meters are simple and highly convenient to use, most of them are not designed to be precision instruments. The possibility of inaccuracies of scale and of ammeter indication is always present, although careful handling and frequent calibration will help to minimize errors of this nature. Furthermore, all light-sensitive cells have certain inherent characteristics which the user must understand if he is to obtain the best possible results:

1. Color Sensitivity. Because most cells do not have spectral response curves like that of the human eye, meters without color correction read accurately only the kind of illumination with which they were calibrated, which is ordinarily light from a filament lamp at a color temperature of 2700°K. Readings of illumination of other spectral distributions may be corrected by applying the proper multiplying factor as supplied by the manufacturer for a particular type of cell when used with a specific light

SPECTRAL RESPONSE
TYPICAL LIGHT-SENSITIVE CELL



Approximate Correction Factors for Unfiltered Light-Sensitive Cells

Illuminant		
Incandescent	1.00	1.00
Fluorescent		
Daylight	.90	.92
4500 White	1.00	1.02
White	1.00	1.12
Soft White	1.00	.95
Green	1.20	1.33
Blue	.53	.52
Pink	.93	1.03
Gold	1.20	1.30
Red	.66	.60
Mercury Vapor	1.15	1.20

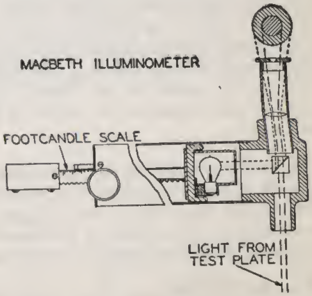
source. The use of a filter which corrects the cell response to a reasonably close approximation of the standard eye sensitivity curve is a more satisfactory and accurate procedure. Some types of meters come equipped with filters which make possible the reading of any color of light with very little error.

2. *Effect of Angle of Incidence.* Light striking the cell face obliquely is partly reflected by the glass cover plate, and does not reach the sensitive cell surface. The rim of the case surrounding the cell also partly shades it for light incident at wide angles, both of these effects increasing with angle of incidence. Since the meters are usually calibrated with light normal to the surface, light from oblique angles or diffuse illumination will give readings lower than the true values. The error may vary from a few per cent with a direct or semi-direct installation where only a small portion of the light is reflected from walls and ceilings, to 10 to 15% with indirect lighting, and as much as 25% where the light comes from side windows only. Certain special meters are provided with diffusing cover plates designed to eliminate this error. Direct light from a single source reaching the cell at an oblique angle can of course be measured by holding the cell perpendicular to the direction of the light and multiplying the reading by the cosine of the angle of incidence.

3. *Fatigue.* All light-sensitive cells exhibit a certain amount of fatigue—that is, a tendency for the meter indication to drop off slowly over a period of minutes, until a constant reading is reached. This effect is most noticeable at high footcandle values, particularly if the cell has just previously been in the dark for some time, or exposed to a much lower level of illumination. Before any measurements are recorded, therefore, the meter should be given as long an adaptation period as may be necessary, at the footcandle level to be measured.

Visual Photometers

Portable visual photometers, in which the brightness of a calibrated test plate placed at the point of measurement is compared visually with a standardized reference lamp, are also used for illumination measurements in the field. The Macbeth illuminometer, the most commonly used instrument of this type, has a photometer head and viewing eyepiece at one end of a light-tight tube which contains a small lamp mounted on a movable rod. When the instrument is sighted at the white test plate, the optical system of the photometer head brings to the eye of the observer a circular central field illuminated by light reflected from the plate, surrounded by a wide ring illuminated by the reference lamp in the tube. Measurements are made by moving the reference lamp back and forth to find the point where the two fields are of equal brightness. A direct footcandle reading is then taken from a scale on the outside of the tube. The scale is so arranged that the indications decrease inversely as the square of the distance between the reference lamp and the head, in accordance with the inverse square law. Calibrated filters, which can be inserted on either side of the head to reduce the brightness of either field, make it



possible to read a wide range of illumination values. Visual photometers, although not so convenient as the cell-type meters, are less susceptible to certain types of error, and when properly used by experienced observers are capable of producing more accurate results.

Brightness Meters

Brightness is usually measured visually, by matching a comparison field inside the meter to the test surface. The Macbeth illuminometer, calibrated in footlamberts or candles per square inch and sighted directly at the test surface, can be used for the measurement of brightness. Small, self-contained instruments designed specifically as brightness meters operate on the same general principle. The brightness of the comparison field in these meters is adjusted by various methods, such as changing the distance of the comparison lamp or varying the current through it, or the use of a graduated neutral filter. By means of a series of neutral filters the range is extended to include the brightnesses of most reflecting and translucent surfaces, and some light sources.

Rough approximations of the brightness values of diffuse reflecting and transmitting surfaces may be obtained with some cell-type footcandle meters. For a reflecting material, the cell is placed against the test surface and then drawn away slowly until a constant reading is obtained (a distance of 2 to 6 inches). The meter indication at that point, multiplied by a factor of 1.25 to correct for light striking the cell at oblique angles, is the approximate brightness in footlamberts. The footlambert brightness of a transmitting surface is similarly measured by placing the cell against the surface and multiplying the reading by 1.25.

Use of Instruments in the Field

Any lighting measurement is determined by the conditions prevailing at the time it is made. For this reason it is always important to observe and record the operating voltage, the cleanliness of the lighting fixtures and of walls and ceilings acting as secondary reflectors, and the length of time the lamps have been burned. This last factor is particularly important with fluorescent and other types of discharge lamps, whose light output changes rapidly during the first few hours of burning. A new fluorescent or mercury vapor installation should burn for at least 100 hours before measurements are made. Electric discharge sources should also be given a warm-up period of at least half an hour, to permit the lamps and all parts of the fixtures to attain a temperature equilibrium before readings are taken.

In making illumination measurements with either the visual or the cell type of meter, the operator must take every precaution against casting shadows on the cell or test plate, or reflecting additional light to it from his clothing. Similarly a surface being measured for brightness must be protected as far as possible from extraneous shadows or reflections.

For footcandle measurements the test surface should be placed as close as possible to the working plane, whether horizontal, vertical, or oblique. Where no definite working area is established, it is customary to take readings on a horizontal plane 30 inches above the floor. It is obvious that a single footcandle determination applies only to the point where it is made, and that for average values over any area a number of readings must be taken. The Illuminating Engineering Society has established

standard procedures for determining average footcandles in large regular areas. Reading locations are specified for several types of lighting installations, and formulas are provided by means of which approximate average illumination over the whole area can be calculated from a comparatively few measurements.

DISTRIBUTION CURVES

Lighting equipment is designed to distribute light in various ways, depending upon the purpose for which it is to be used. This distribution of light can be represented either graphically or numerically by several methods, the most common of which is the *candlepower distribution curve.*

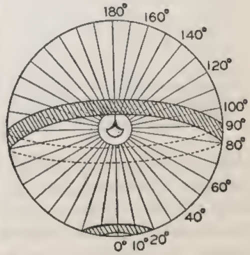
A candlepower distribution curve is the result of taking candlepower measurements at various angles around a light source or luminaire, and plotting them in graph form, usually on polar coordinates. The distance of any point on the curve from the center indicates the candlepower of the source in that direction.

The illumination received from a single light source on any given surface can be calculated from candlepower distribution data on the source. Where the relationship between source size and source-to-surface distance is such that inverse square conditions apply, the calculation merely involves reading from the distribution curve the candlepower at the required angle, dividing by the square of the distance in feet, and multiplying by the proper trigonometric function if the surface is not perpendicular to the direction of the light rays coming from the source. (See section on Illumination in preceding table. Additional information is given in Chapter Six, under Point-By-Point Method.) Where the size of the source prohibits the direct use of the inverse square law, a somewhat more involved calculation process is required.

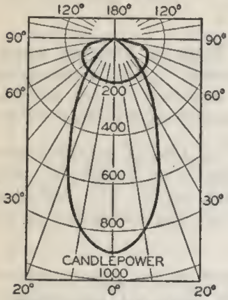
Where the candlepower distribution is symmetrical about an axis, the light output of the source in terms of lumens can be obtained from an average candlepower distribution curve. The curve is divided into equal zones, usually of ten degrees each, and the candlepower at the mid-point of each one is taken as the average value for the zone and multiplied by a zonal factor which converts it directly to the number of lumens in the zone. Because the candlepower toward the center of the curve is much more effective in determining the total light output of the source than the candlepower at either end, the zonal lumen factors are based on the relative

LUMEN CONSTANTS
For Ten-Degree Annular Zones

Zone	Mid-Zone Angle	Zone	Mid-Zone Angle	Lumen Constant
0°-10°	5°	170°-180°	175°	0.095
10°-20°	15°	160°-170°	165°	0.283
20°-30°	25°	150°-160°	155°	0.463
30°-40°	35°	140°-150°	145°	0.628
40°-50°	45°	130°-140°	135°	0.774
50°-60°	55°	120°-130°	125°	0.897
60°-70°	65°	110°-120°	115°	0.993
70°-80°	75°	100°-110°	105°	1.058
80°-90°	85°	90°-100°	95°	1.091



areas of the angular zones on the surface of an imaginary sphere circumscribed about the source. The sum of the zonal lumen factors from 0° to 180° is 4π or 12.57. Thus a source emitting one candle uniformly in all directions would prove to produce a total of 12.57 lumens, as stated in the Terminology and Measurements table earlier in the chapter.



TWO DISTRIBUTION CURVES OF EQUAL LUMEN OUTPUT

Because of these angular relationships, the area within a distribution curve is by no means a measure of the total light output of the source. Two units which produce exactly the same number of lumens may distribute the light quite differently, and have candlepower curves of entirely different shapes and areas.

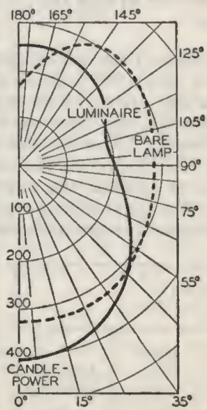
For a general lighting luminaire, the distribution of the light between the lower and upper hemispheres is the basis on which the equipment is classified as *direct*, *semi-direct*, *general diffuse*, etc. (see Chapter Four). For this purpose the sums of the lumens below 90° and above 90° are expressed as percentages of the sum of the total lumens from 0° to 180°. *Luminaire efficiency* is the ratio, expressed in per cent, of the total lumens emitted by the luminaire to the total lumens generated by the bare lamp.

A candlepower distribution curve for a typical enclosing globe is illustrated, with the bare lamp curve for purposes of comparison. The candlepower of the luminaire for each mid-zone angle from 0° to 180° is listed in the table and plotted on the graph, and the lumens calculated for each zone by application of the zonal lumen factors are also shown. This particular enclosing globe, equipped with a 200-watt lamp, produces 1760 lumens below the horizontal (0°-90°) and 1349 lumens above. Therefore in the lower hemisphere the luminaire emits 47.5% (1760/3700) of the lumens produced by the bare lamp, and in the upper hemisphere 36.5% (1349/3700). The sum of these two percentages, or the ratio of the total lumens produced by the fixture to the lumen output of the bare lamp (3109/3700), gives a *luminaire efficiency* of 84%. The manner in which the luminaire distributes its light between the two hemispheres is determined by dividing the sums of the lumens below 90° and above 90° by the total luminaire lumens: 1760/3109 = 57%, 1349/3109 = 43%. Thus

AVERAGE VERTICAL CANDLEPOWER DISTRIBUTION
TYPICAL WHITE GLASS ENCLOSING GLOBE
200-WATT INSIDE FROSTED LAMP - 3700 LUMENS

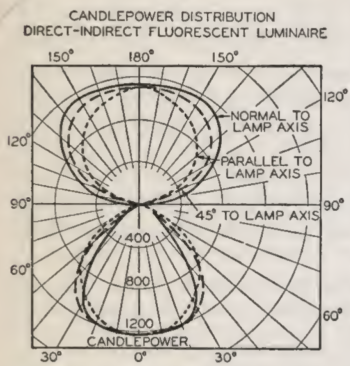
LUMINAIRE DISTRIBUTION DATA		
MID-ZONE ANGLE	CANDLE-POWER	LUMENS
0°	407	
5°	407	39
15°	393	111
25°	375	174
35°	350	220
45°	323	250
55°	282	253
65°	250	248
75°	225	238
85°	208	227
90°	200	
TOTAL	0°-90°	1760
95°	197	215
105°	197	208
115°	199	198
125°	208	187
135°	224	173
145°	244	153
155°	256	119
165°	255	72
175°	249	24
180°	249	
TOTAL	90°-180°	1349
TOTAL	0°-180°	3109

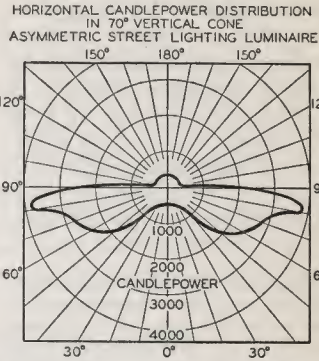
LUMINAIRE EFFICIENCY - 84%
(3109/3700)



this luminaire directs 57% of its light below the horizontal, and 43% above.

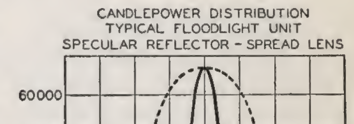
The candlepower distribution of units which are not symmetrical about an axis cannot be so simply represented. For fluorescent fixtures at least two curves, one in the plane parallel to the long axis of the lamp and one normal to it, are shown, and sometimes more. With some types of equipment, as for example many street lighting luminaires, horizontal candlepower distribution is important, and measurements are made in lateral





planes. Where the degree of asymmetry is not too great, as in most fluorescent fixtures, a fairly representative average candlepower distribution curve can be obtained, and efficiency can be computed from it. The efficiency of a highly asymmetric unit can be calculated from a sufficient number of candlepower curves, but the procedure is more complicated.

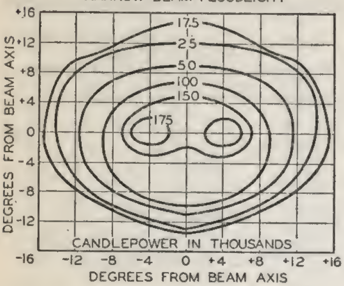
Candlepower distribution data on beam-producing equipment such as spotlights and floodlights are commonly plotted on rectilinear rather than polar coordinates, angular distance from the center of the beam being indicated along the base line and candlepower by the ordinates. If the distribution is symmetrical about a central axis, one curve represents the beam. An asymmetric beam requires at least one vertical and one horizontal traverse, and sometimes more, for a complete description.



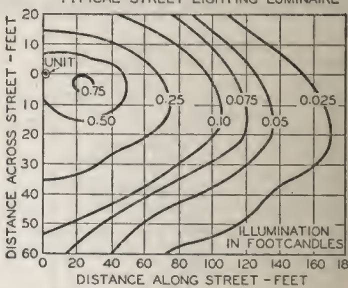
An irregular beam pattern is often best represented by means of an *isocandle diagram*. Here a large number of candlepower readings are plotted against degrees from the beam axis, both horizontal and vertical, and lines are drawn connecting equal candlepower values, as isobars or isotherms are drawn on a weather map. Isocandle diagrams involving wide-angle spreads are sometimes plotted on a web representing one side of a sphere, where the areas of the zones are shown more accurately than on rectilinear coordinates.

An *isolux* or *isofootcandle diagram* is a group of curves drawn through points receiving the same amount of illumination on the working surface. Isolux curves for several different mounting heights are sometimes combined in one diagram by expressing the distances on the working plane as

ISOCANDLE DIAGRAM
NARROW BEAM FLOODLIGHT



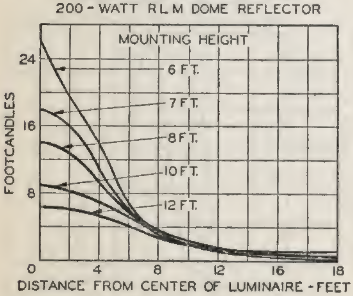
ISOLUX DIAGRAM
TYPICAL STREET LIGHTING LUMINAIRE



multiples of the mounting height. Correct footcandles for other mounting heights may then be obtained by multiplying the values given on the curves by the ratio of the square of the present mounting height to the square of the new mounting height. The isolux diagram illustrated is for a single lighting unit, but similar curves for installations can be readily computed by summing the footcandles received at any given point from each luminaire contributing illumination to that location.

Each different mounting height, or distance between luminaire and working plane, produces a different isolux diagram. An isocandle diagram, on the other hand, is a fixed characteristic of the luminaire, independent of distance or mounting height. Isocandle diagrams are perhaps most commonly used for the representation of headlight, floodlight, and spotlight beams, and isolux diagrams for street lighting installations, although either can be used for any type of lighting equipment.

FOOTCANDLE DISTRIBUTION DATA
200-WATT RLM DOME REFLECTOR



The distribution of illumination from a source may also be represented by plotting, for various source-to-working-plane distances, curves of footcandles against distance from the source center. Where the candlepower distribution is irregular or asymmetric this method is much less satisfactory than the isolux diagram, and its use is commonly confined to equipment whose distribution is approximately symmetrical.

CHAPTER THREE
LIGHT SOURCES

The primary purpose of a light source is the production of light, and the efficiency with which a lamp fulfills this purpose is expressed in terms of lumens emitted per watt of power consumed. If a source could be developed that would radiate all the energy it received as monochromatic yellow-green light in the region of maximum sensitivity of the eye, 5550 Angstroms, it would produce approximately 650 lumens for each watt of power consumed. A theoretical source of white light of maximum efficiency, emitting only visible energy without any infrared or ultraviolet, would produce about 200 lumens per watt. Compared with these figures the best available lamp efficiencies today seem disappointingly low. However, reference to earlier products of lamp manufacture shows the progress that has been

EFFICIENCIES OF VARIOUS LIGHT SOURCES
Approximate Lumens per Watt

Candle (Luminous Efficiency Equivalent)	0.1
Oil Lamp (Luminous Efficiency Equivalent)	0.3
Original Incandescent Lamp (1879)	1.4
60-Watt Carbon Filament Lamp (1905)	4.0
60-Watt Coiled Coil Tungsten Filament Lamp (1947)	13.9
1000-Watt General Service Lamp (1947)	21.5
No. 1 Photoflood Lamp (1947)	34.6
400-Watt A-H1 Mercury Vapor Lamp (Lamp Only) (1947)	40.0
40-Watt White Fluorescent Lamp (Lamp Only) (1947)	58.0

made. The efficiency of the 60-watt lamp, for example, has been increased almost 350 per cent during the past 40 years by changing from carbon to tungsten as a filament material, from vacuum to gas-filled construction, and from straight filament wire to coiled and then coiled coil filaments.

However, the filament lamp has certain characteristics which make it inherently inefficient as a source of light, and although it is probable that efficiencies will still be raised slightly by further refinements in manufacturing processes, the maximum possible values have already been approached. For any considerable increase in efficiency it is now necessary to turn to another type of light source, the electric discharge lamp. Present mercury vapor lamps have efficiencies of 40 to 65 lumens per watt, and sodium vapor lamps 55 lumens per watt, while fluorescent lamps have already reached figures as high as 58 lumens per watt, with every likelihood of further increases.

HISTORY OF LAMP COST*

1907	Carbon Filament Vacuum	$4.62
1910	Straight Tungsten Filament Vacuum	2.13
1926	Coiled Tungsten Filament Gas-Filled	.45
1947	Coiled Coil Tungsten Filament Gas-Filled	.13

* Cost of 60-Watt General Service Lamps to Produce One Million Lumen-Hours of Light.

As a result of decreasing lamp prices, as well as consistently increasing efficiencies, lamp cost per unit of light generated for a watt of power consumed has steadily decreased throughout the history of lamp manufacture. What the future may bring is impossible to foretell, but it is probable that with the relatively new electric discharge lamp we stand at the beginning of a new era of increased efficiencies and lowered lighting costs.

FILAMENT LAMPS

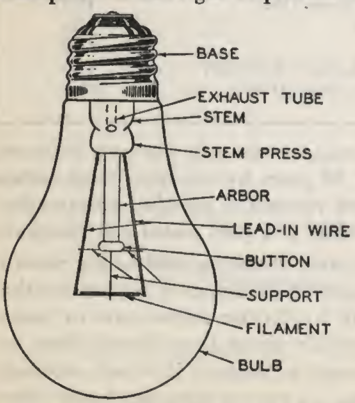
The filament lamp produces light by virtue of a wire or filament heated to incandescence by the flow of electric current through it.

PRINCIPAL PARTS OF A LAMP

The three major parts of a filament lamp are the bulb, the base, and the filament.

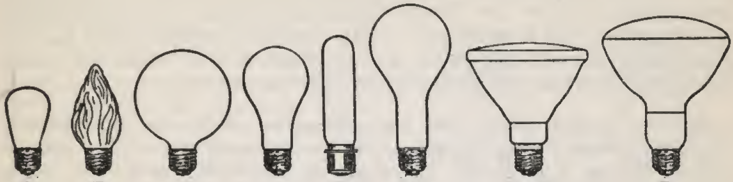
Bulb

Since an incandescent filament must operate in either a vacuum or an atmosphere of inert gas to prevent rapid disintegration due to oxidation, it is enclosed in a sealed glass envelope called the *bulb.* Various kinds of glass are used, depending on the type of lamp and its application. Most general lighting service lamp bulbs are made from lime (soft) glass. Special service lamps with bulbs of hard, or heat resisting, glass are used in applications where rain or snow coming into contact with the hot bulb might cause a soft glass bulb to crack. Hard glass is also necessary for projection lamps, spotlight lamps, etc., which commonly have higher bulb operating temperatures than general service lamps.



Bulb Size and Shape—The sizes and shapes of lamp bulbs are designated by a letter or letters followed by a number. The letters indicate the shape of the bulb: S = Straight Side, F = Flame, G = Round or Globular, T = Tubular, PS = Pear Shaped, PAR = Parabolic, R = Reflector, A = Arbitrary designation applied to the bulbs commonly used for general lighting service lamps of 100

watts or less. The number in a bulb designation indicates the diameter of the bulb in eighths of an inch. For example, "T-10" indicates a tubular bulb having a diameter of 10/8 or 1¼ inches.



Bulb size and shape are determined by the purpose for which the lamp is to be used. Obviously the larger the bulb the greater the area over which tungsten vaporized from the filament will be distributed as the lamp ages and gradually blackens. The thinner this deposit the less light it absorbs, and the better the light output of the lamp throughout life. From the standpoint of lighting equipment cost, however, there is a limit to desirable bulb size, and the size of a general lighting service lamp is usually a compromise between performance and economic considerations. In projection lamps and certain other types where minimum size outweighs maintenance of light output, bulbs often are smaller than those for general lighting service lamps of equal wattage ratings.

Bulb Finish and Color—The most common bulb finish is the *inside frost*, a very light acid etching applied to the inner surface of the bulb. This process diffuses the light from the filament and leaves the outer surface of the bulb smooth and easily cleaned, without absorbing any appreciable amount of light. Opal glass bulbs or bulbs with a ceramic white finish provide greater diffusion at the expense of greater light absorption. Inside frosted lamps are preferred for most general lighting purposes where diffusion is desirable, but optical systems designed for accurate control of light by reflection or refraction require a small light source, and therefore a clear bulb lamp.

Other finishes applied to some general lighting service lamps are *white bowl* and *silvered bowl*. A white bowl lamp has a translucent white coating on the inner surface of the bulb bowl, which serves to reduce both direct and reflected glare from open fixtures. A silvered bowl lamp has an opaque silver coating applied to the outside of the bowl. The inner surface of this coating is a highly specular reflector which is not affected by dust or deterioration, and therefore remains efficient throughout the life of the lamp. Silvered bowl lamps are commonly used in certain types of equipment for totally indirect lighting, and also occasionally in direct fixtures such as RLM reflectors.

Colored light is obtained from filament lamps by the subtractive method; that is, by means of a separate filter or a bulb so processed that light of colors other than that desired is largely absorbed. Colored bulbs used in lamp manufacture are of three types: natural, inside or outside spray coated, and ceramic glazed. Natural colored bulbs, wherein chemicals are added to the ingredients of the glass to produce the desired color, are regularly available in daylight blue, blue, amber, green, and ruby. Of these colors, daylight blue is the most widely used. The characteristics of the daylight blue bulb are such as to reduce the preponderance of red

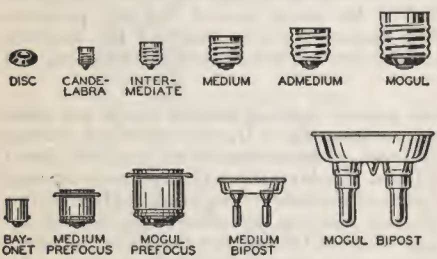
and yellow light common to incandescent lamps, with the result that the light produced more nearly approaches daylight in color. Since this is accomplished at the expense of increased lamp cost and of some 35% absorption in light, daylight blue lamps should be used only where the lighting requirements make it necessary. Natural colored bulbs produce light of purer colors than coated bulbs, and are often used in preference to the latter for theatrical and photographic lighting purposes.

Because of their lower cost and general suitability for the purpose, coated or ceramic glazed lamps are to be preferred where decorative or display lighting is involved. The colors in most common use are: white or all frosted, red, blue, green, yellow, amber-orange, ivory and flametint. Outside spray coatings are not permanent, and should be used only where protected from the weather. Inside coated or ceramic glazed lamps may be used with equal satisfaction either in or outdoors.

For temporary use, lamps are sometimes colored by dipping the bulbs in a special transparent or translucent lacquer. Like outside coated lamps, they are unsuited for continuous use out of doors.

Base

The base provides a means of connecting the lamp bulb to the socket. For general lighting purposes, screw-type bases are most commonly used. Most general lighting service lamps (three hundred watts and below) have medium screw bases. The higher wattages (three hundred watts and above) use the mogul screw base. Some of the lower wattage lamps, particularly the sign, indicator, and decorative types, are made with candelabra or intermediate screw bases.



Medium prefocus and mogul prefocus bases are used where accurate positioning of the light source (the lamp filament) with respect to an optical system is required. A medium bipost or mogul bipost base, usually used on high wattage lamps, consists of two metal pins or posts imbedded in a glass "cup" forming the end of the lamp bulb. Most screw and prefocus bases are attached to the bulb by means of a basing cement especially designed for the purpose. Some of the higher wattage genera lighting and special service mogul screw base lamps use what is known as a *mechanical* base which requires no basing cement. Mechanical bases involve the use of specially formed glass seals with "dimples" into which protrusions of an inner base shell fit and are held in place. The regular outer base shell is screwed onto the threaded inner shell and the two interlocked by means of holes punched through both shells.

Filament

The filament is the light-producing element of the lamp, and the primary considerations in its design are its electrical characteristics. The wattage of a filament lamp is equal to the voltage delivered at the socket times the amperes flowing through the filament. By Ohm's Law ($I=E/R$) the current (amperes) is determined by the voltage and the resistance, which in turn depends on the length and the diameter of the filament wire. The higher the *wattage* of lamps of the same *voltage*, the higher the current and therefore the greater the diameter of the filament wire required to carry it. The higher the *voltage* of lamps of the same *wattage*, the lower the current and the smaller the diameter of the filament wire.

32-VOLT 1000-WATT FILAMENT 120-VOLT 1000-WATT FILAMENT

The higher the operating temperature of the filament, the greater the share of the emitted energy that lies in the visible region of the radiation spectrum. Since most filament lamps radiate as light only about 10 to 12% of the input energy, it is important to design a lamp for as high a filament temperature as is consistent with satisfactory life. Carbon, which has a higher melting point than tungsten and was one of the early filament materials, has been almost completely replaced by tungsten because carbon at high temperatures evaporates too rapidly, whereas tungsten combines the properties of high melting point and slow evaporation.

MELTING POINTS

Tungsten	3410°C	6170°F
Carbon	3700°C	6692°F

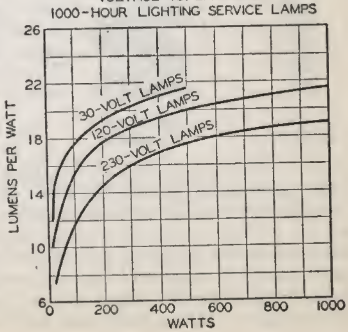
Since the larger the diameter of the filament wire the higher the temperature at which it can be operated without danger of excessive evaporation, high-wattage lamps are more efficient than low-wattage lamps of the same voltage and life rating. A 100-watt 120-volt general lighting service lamp, for example, produces 57% more light than four 25-watt 120-volt lamps consuming the same wattage. It also follows that low-voltage lamps, because their filament wire diameter is greater, are more efficient than higher-voltage lamps of the same wattage.

APPROXIMATE FILAMENT TEMPERATURES

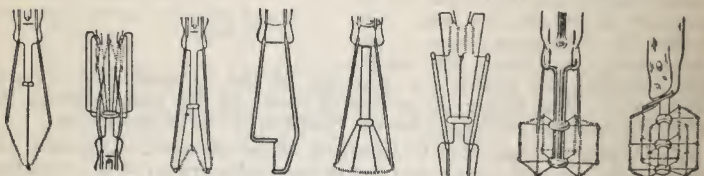
Watts	°C
40*	2475
60*	2500
100*	2575
200*	2620
300*	2665
500*	2670
1000*	2720
1500*	2765
No. 1 Photoflood	3160

* Standard 120-Volt General Lighting Service Lamps.

VOLTAGE VS. EFFICIENCY
1000-HOUR LIGHTING SERVICE LAMPS



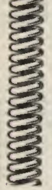
The filament forms in common use today are designated by a letter or letters indicating whether the wire is straight or coiled, a number specifying the general form of the filament, and sometimes another letter indicating arrangement on the supports. S as the first letter of a filament designation means a straight (uncoiled) filament wire, C a coiled wire, CC a coiled coil, and R a flat or ribbon-shaped wire. The numbers and other letters assigned to the various filament forms are purely arbitrary.



NO.2V NO.5 NO.7A NO.8 NO.9 NO.13 NO.17 NO.22

Early lamps were made with straight filaments operating in a vacuum. When inert gases were introduced into the bulb, it was found that coiling the wire decreased the effective surface exposed to the circulating gas, and therefore reduced the heat lost by conduction and convection. The coils also tend to heat each other, and the coiled filament is mechanically stronger. Today nearly all types of lamps, both vacuum and gas-filled, have coiled filaments. The single coil (C) filament is formed by winding the tungsten wire on a mandrel of steel or molybdenum in a continuous process. The coil with the mandrel still in place is cut into the desired lengths and immersed in an acid bath which dissolves the mandrel but does not attack the tungsten.

Coiled coil, or double-coiled, filaments which provide increased efficiency and reduced light-source size are at present used in 50-, 60-, and 100-watt standard-voltage general lighting service lamps, and in certain types of projection lamps. The process of making coiled coil filaments is the same as that for single coil filaments except that the single coil with the mandrel intact is wound onto another mandrel which is later "retracted," or removed mechanically. The first mandrel is then removed from the coiled coil by dissolving.



COILED FILAMENT

COILED COIL FILAMENT

In the general lighting service type of lamp the arrangement of the filament coil and its supports is dictated by the limiting size of the bulb neck through which it must be inserted, and by other manufacturing considerations. Lamps for special purposes often require certain filament forms. For projection, searchlight, spotlight, floodlight and similar services where accurate control of light demands a small source, the filaments are concentrated into as small a space as possible. In contrast, for showcase service where a long light source is needed, the filament may be extended along almost the full length of the bulb.

Filling Gas

Incandescent lamps were first made with evacuated bulbs, the purpose being merely to keep the filament from burning up by excluding oxygen. Later it was discovered that the pressure exerted on the filament by an inert gas introduced into the bulb retarded the evaporation of tungsten, thus making it possible to design lamps for higher filament temperatures. Vacuum lamps are now designated as "*type B*" lamps, gas-filled lamps as "*type C.*"

The gas removes some heat from the filament, as a result of conduction and convection losses not present in the vacuum lamp. The larger the surface of the wire in proportion to its volume or mass, the greater this cooling effect becomes, until eventually it nullifies the gain achieved by using the filling gas. Filaments with a current rating of less than one-third ampere have a wire diameter so small that the introduction of gas is a disadvantage rather than an advantage. For this reason, standard-voltage general lighting service lamps of less than 40 watts are of the vacuum or type B construction, while lamps of 40 watts and higher are gas-filled.

Nitrogen and argon are the gases most commonly used in lamp manufacture. Projection lamps use an atmosphere of 100% nitrogen. Most other types have a mixture of nitrogen and argon, the proportions varying with the lamp and the service for which it is designed. High-voltage lamps, for example, are filled with approximately 50% argon and 50% nitrogen, the higher wattage standard-voltage types about 88% argon and 12% nitrogen, and the lower wattage standard-voltage types and all street series lamps about 98% argon and 2% nitrogen. Some nitrogen is necessary to prevent arcing across the lead-in wires, which would occur if pure argon were used. The greater the inherent tendency of a lamp to arc, the higher the percentage of nitrogen in its gas mixture.

Krypton is a relatively rare and expensive gas which has a higher atomic weight than either argon or nitrogen, and therefore causes less energy loss by conduction and convection. It is used in small quantities in certain miniature lamps such as miner's cap lamps, where the limited capacity of the battery power supply makes it essential to obtain the greatest possible efficiency. Hydrogen, because of its low atomic weight, is used in certain very special types of flashing signal lamps where rapid cooling of the filament is important.

ATOMIC WEIGHTS OF GASES	
Hydrogen	1.008
Nitrogen	14.008
Argon	39.944
Krypton	83.7

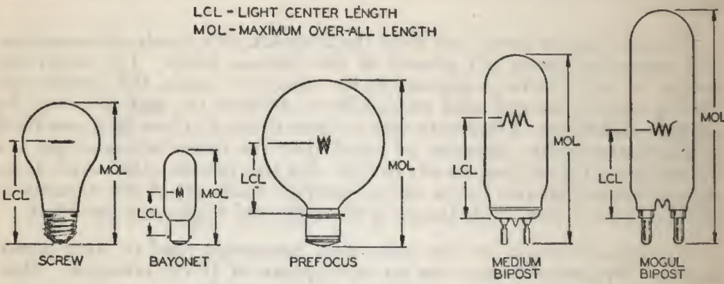
Physical Dimensions

In addition to the diameter of the lamp, which is given in eighths of an inch in the bulb designation, two other dimensions which are important are the maximum over-all length of the lamp, and the light center length.

The *over-all length* of a lamp is measured from the end of the base to the far end of the bulb. The published over-all length of a lamp is a *maximum* dimension. In other words, the length of the lamp will not exceed that figure, but may be less. In the design of equipment it is often necessary to

know the minimum as well as the maximum over-all length to be expected in a lamp of a given type. This information, as well as other data on physical dimensions and tolerances, may be obtained from the lamp manufacturer.

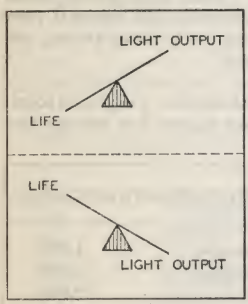
The *light center length*, which is most important in equipment where accurate control of light is required, is measured from the center of the light source to a designated point on the base which varies with the type of base.



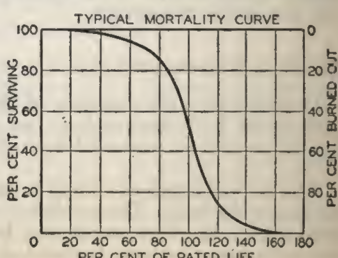
OPERATING CHARACTERISTICS

Light Output vs. Life

Both the life of a lamp and its light output are determined by its filament temperature. The higher the temperature for a given lamp, the greater the efficiency (lumens emitted per watt of power consumed) and the shorter the life. Hence light output and life are interdependent. A lamp can be designed for a long life at the expense of light output, or for high light output at the expense of life. In practice the life for which a lamp is designed is an economic balance between the two factors, determined on the basis of the purpose for which the lamp is to be used.



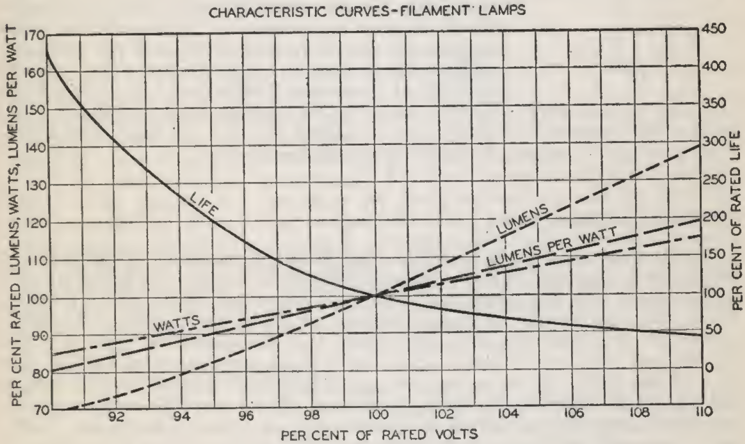
Obviously, the quality or value of a lamp cannot be judged by its life alone. Lamp life may be as short as 10 to 50 hours for projection lamps and 3 hours for photoflood lamps, where high light output is the dominant requirement, replacement is convenient, and life is of relatively little consequence. Or it may be as long as 2000 to 3000 hours for street lighting lamps, where the high cost of replacing burned out lamps justifies relatively low efficiencies. For general lighting service lamps, which are used for long hours and yet are comparatively easy to replace, a life of 750 or 1000 hours has become the accepted standard.



Published data on lamp life refer to the *average* life of a group of lamps under specified test conditions, and are not intended as a guarantee of the performance of any individual lamp. As shown by the accompanying mortality curve, in any large group of lamps some will fail relatively early in life, whereas others will still be burning long after the end of rated life.

Over or Undervoltage Operation

As a general rule, lamps should be burned at rated voltage. Overvoltage operation results in higher wattage, higher efficiency, and higher light output, but shorter lamp life. Undervoltage burning, while increasing lamp life, causes a reduction in wattage, in efficiency, and in light output. A voltage as little as 5% below normal results in a loss of light

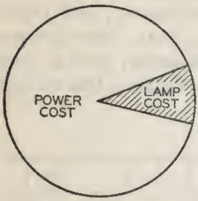


amounting to more than 16%, with a saving in wattage of only 8%. Since lamp cost is almost always small compared with the cost of the power to operate the lamp, the increased lamp life which accompanies reduced voltage does not begin to compensate economically for the loss in light output. Maintenance of the proper voltage is therefore an important factor in obtaining good performance from lamps and lighting installations.

However, there are cases where it is more economical to operate lamps at higher than rated voltage. The cost of power, the cost of fixtures and wiring, and the cost of lamps must all be taken into consideration, along with the increased light output, in estimating the possible advantages of overvoltage operation. The power cost must be computed on the basis of the increased wattage at the higher voltage, and the figure for lamp cost must take into account the shortened life as well as the cost of lamp replacement. In some cases the higher light output may make possible a reduction in the number of lighting units required.

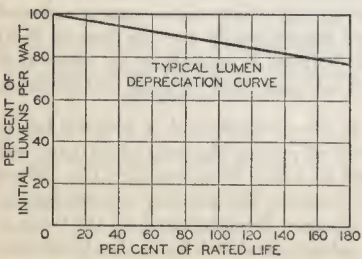
Where the hours of burning for a season or period are relatively short and the energy cost is comparatively high, and particularly where the lamps are replaced in a group before burnout, careful analysis may reveal a definite saving in operating the lamps at overvoltage. These conditions are often encountered in certain types of sports lighting, where it is fairly common practice to use lamps of a lower rated voltage, as for example 110-volt lamps on a 120-volt circuit.

Any calculation of lamp and energy costs emphasizes the fact that the cost of lamps is nearly always a minor consideration compared to the cost of power. Under ordinary circumstances, the lamps represent less than 10% of the cost of lamps and energy combined. It is for this reason that the efficiency of a lamp is more important than its price, and low-efficiency sources should not be used except in special cases where long life is a consideration. For this reason also it is more economical to discard lamps that have been in service a long time and are seriously blackened than to continue to operate them to burnout at their depreciated efficiency. In many cases it is desirable to replace all the lamps in an installation at the same time, before the majority of them have reached the end of their useful life. This practice is commonly called *group replacement.*



Lumen Maintenance

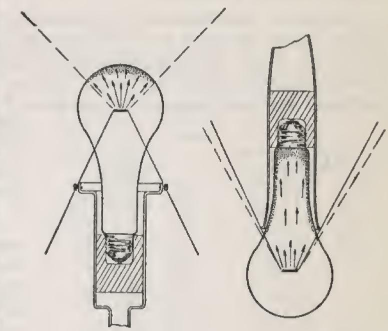
As an incandescent lamp burns, the filament gradually evaporates or sublimates, causing a slow but continuous reduction in wattage and light output as it decreases in diameter. The normal end of life is reached when the wire breaks or burns through at its thinnest spot. A further reduction in light output results from the absorption of light by the sublimated tungsten, which collects as a black deposit on the inner surface of the bulb. Some projection and bipost base general service lamps are provided with screens or grids located above the filament to collect the blackening as it is carried upward by the gas currents within the bulb, and prevent it from being deposited on the bulb walls. Use of a collector screen materially improves the lumen maintenance of a lamp, and makes it possible to employ a smaller bulb than would otherwise be feasible. Some high-wattage high-efficiency lamps are made with a small amount of loose tungsten powder in the bulb which can be shaken around to clean the blackening from the inner surface of the glass by a scouring action.



Lamp manufacturers' data published on standard lamps include, in addition to initial efficiency, the efficiency at 70% of rated life. Inasmuch as the light depreciation curve is essentially a straight line, a line drawn through the initial efficiency at zero life and the efficiency at 70% life may be used to determine the lumens per watt of a given lamp at any point in life.

Burning Position

With some few exceptions general lighting service lamps may be burned in any position. However, the lumen maintenance of type C lamps is best when they are burned base up. This is because the tungsten blackening is conducted upward by the gas and is always deposited above the filament. When the lamp is burned base up, the blackening collects in the area of the bulb adjacent to the base, where the light is already partially intercepted by the base, socket, and luminaire husk. If the lamp is burned base down, the blackening collects in the bowl of the bulb, where it causes a much greater reduction in light output. Lamps burned in a horizontal position are affected similarly.



Certain types of lamps, particularly projection, spotlight, floodlight and some street series lamps, are not designed for universal burning and should always be used in the position designated by the manufacturer's published data. The reason for this may be the construction of the filament, which would be likely to sag or short-circuit if burned in a position other than that for which it is designed. Or operation in an incorrect position sometimes places the filament directly under a glass part which might be softened by the heat. If a lamp containing a collector grid is burned in any other position than with the grid directly above the filament, the special construction will not be effective in controlling blackening.

Base and Bulb Temperatures

Operation of lamps under conditions which cause excessive bulb and base temperatures may result in melting of the bulb, softening of the base cement and loosening of the base, or in extreme cases damage to the socket and adjacent wiring. Most fixtures are properly designed to dissipate the heat generated by the lamps, but severe conditions such as might be induced by overvoltage operation, or the use of lamps of higher wattage than the manufacturer's rating, may give rise to difficulty. If metal parts of shades, reflectors, or fixtures are allowed to come in contact with the bulb of a gas-filled lamp, the local cooling effect may result in glass cracks which will cause lamp failure (sometimes violent).

For best lamp performance the maximum safe operating temperature of a soft or lime glass bulb is in the neighborhood of 300°C. Hard glass bulbs of filament lamps may operate at temperatures as high as 435° to 475°C, depending upon the exact type of glass used. The temperature of cemented bases should not exceed 175°C for continuous operation. Mechanical bases will withstand temperatures approximately 50° higher.

MAXIMUM SAFE OPERATING TEMPERATURES
(Approximate Figures)

Soft Glass Bulb	300°C
Hard Glass Bulb	435°C—475°C
Cemented Base	175°C
Mechanical Base	225°C
Bipost Base	285°C

Gas-filled lamps, because of the convection currents within the bulb, have higher bulb temperatures than vacuum lamps. Therefore vacuum lamps are preferable for use in exposed outdoor locations, where snow or rain may strike the hot bulb. Gas-filled lamps exposed to the elements should have hard or heat resisting glass bulbs.

Vibration and Shock

Tungsten wire heated to incandescence becomes somewhat soft and pliable, and filament coils may be distorted or broken if the lamp is subjected to shock or vibration while burning. Vibration, especially of the low-amplitude high-frequency variety, is an insidious enemy of satisfactory lamp performance, and should be guarded against wherever possible. There are available a number of commercial sockets and fixtures designed to protect the lamps by absorbing vibration.

VIBRATION SERVICE FILAMENT

ROUGH SERVICE FILAMENT

Where vibration cannot be eliminated by these means, special *vibration service* lamps, provided with extra filament supports, should be used. The construction of vibration service lamps is such that they will give most satisfactory performance if burned in a vertical position, either base up or base down. They should never be used where they are likely to receive extreme shocks.

For use on extension cords, and in any service where excessive shocks may be encountered, there are available *rough service* lamps with a special type of shock-resisting filament construction. Rough service lamps are designed to operate in any burning position, and may be used in place of vibration service lamps where it is necessary to burn lamps horizontally. Both vibration and rough service lamps sacrifice some efficiency to strength of construction, and are more expensive than standard lamps; they should, therefore, be used only where required by service conditions.

LUMEN OUTPUTS
VIBRATION AND ROUGH SERVICE
120-VOLT LAMPS

Watts	Service	Lumens
50	General	660
50	Vibration	550
50	Rough	455
100	General	1630
100	Vibration	1300
100	Rough	1200

TYPES OF LAMPS

General Lighting Service Lamps

The familiar general lighting service lamps, from the 15-watt A-15 to the 1500-watt PS-52, designed for multiple burning on 115-, 120-, or 125-volt circuits, are the most commonly used filament-type lamps. All

standard general service lamps are equipped with screw bases. The larger wattages are manufactured in either clear or inside frosted bulbs. Below 150 watts, inside frosted lamps are standard. Certain modifications, such as hard glass bulbs for the larger, and clear bulbs for the smaller, lamps are available on special order.

TECHNICAL DATA ON REPRESENTATIVE 120-VOLT STANDARD FILAMENT LAMPS

GENERAL LIGHTING SERVICE LAMPS

Watts	Bulb	Base	Filament Construction	Rated Average Life (Hours)	Approx. Initial Lumens	Lumens per Watt	
						Initial	70% Life
25	A-19	Medium	C-9	1000	260	10.5	9.0
40	A-19	Medium	C-9	1000	470	11.7	10.7
50	A-19	Medium	CC-6	1000	665	13.3	12.5
60	A-19	Medium	CC-6	1000	835	13.9	13.2
75	A-21	Medium	C-9	750	1120	14.9	13.5
100	A-21	Medium	CC-6	750	1630	16.3	15.3
100	G-30	3-Contact Mogul	2 C-2R	1000	1410	14.1	....
200	G-30	3-Contact Mogul	2 C-2R	1000	3350	16.7	....
300	G-30	3-Contact Mogul	2 C-2R	1000	4760	15.8	....
150	PS-25	Medium	C-9	750	2600	17.3	15.6
200	PS-30	Medium	C-9	750	3700	18.5	16.4
300	PS-30	Medium	C-9	750	5900	19.7	17.3
300	PS-35	Mogul	C-9	1000	5650	18.8	16.7
500	PS-40	Mogul	C-7A	1000	9950	19.9	17.0
750	PS-52	Mogul	C-7A	1000	15500	20.6	17.6
1000	PS-52	Mogul	C-7A	1000	21500	21.5	17.4
1500	PS-52	Mogul	C-7A	1000	33000	22.0	15.6

LUMILINE LAMPS

Watts	Bulb	Length (Inches)	Base	Filament Construction	Rated Average Life (Hours)	Approx. Initial Lumens	Initial Lumens per Watt
30	T-8	17¾	Disc	C-8	1500	245	8.2
40	T-8	11¾	Disc	C-8	1500	345	8.7
60	T-8	17¾	Disc	C-8	1500	550	9.2

PROJECTOR AND REFLECTOR LAMPS

Watts	Bulb	Base	Filament Construction	Rated Average Life (Hours)	Initial Max. Beam Candle-power	Approx. Initial Zone Lumens	Descrip-tion
Projector							
150	PAR-38	Med. Skt.	CC-6	1000	10500	990(0-15°)	Spot
150	PAR-38	Med. Skt.	CC-6	1000	2500	1150(0-30°)	Flood
Reflector							
150	R-40	Medium	C-11	1000	7000	700(0-15°)	Spot
300	R-40	Medium	CC-2V Horiz.	1000	16000	1460(0-15°)	Spot
150	R-40	Medium	C-11	1000	1200	700(0-30°)	Flood
300	R-40	Medium	CC-2V Horiz.	1000	3000	1620(0-30°)	Flood

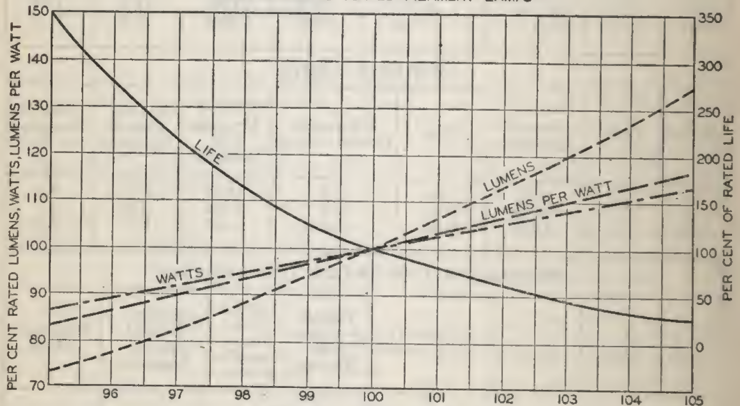
High and Low Voltage Lamps

Lamps similar to the general lighting service line are available for operation on 230 and 250 volts. The low efficiency of these lamps as compared to like lamps of standard-voltage rating has already been mentioned. Other disadvantages resulting from the smaller filament wire diameter of high-voltage lamps are reduced mechanical strength, and larger over-all light-source size, which makes them less satisfactory for use in floodlight and projection equipment. The only gain achieved by the industrial use of these higher voltages is the reduction in ampere load which results from doubling the voltage, and the consequent saving in wiring cost. Lamps for operation on 30- and 60-volt circuits are also available for use in train lighting and in country home service.

Series Burning Lamps

Most lamps are designed to operate on a multiple circuit. Some, however, such as most of the lamps used for street and street railway car lighting, are designed for operation on a series circuit. Street series lamps are commonly rated in lumens and amperes instead of watts and volts, as are multiple lamps. All of the lamps in a series circuit should be of the same current (ampere) rating. The wattage, light output, and life of series lamps are materially affected by variations in operating current, and close regulation of current to design values is a major factor in satisfactory lamp performance.

CHARACTERISTIC CURVES-FILAMENT LAMPS



For continuity of operation, some provision must be made in a series circuit so that the failure of one lamp does not break the circuit and extinguish all the lamps. Some street railway lamps have a cut-out device incorporated in the lamp itself, so that a burned out lamp is shorted out of the circuit. Where such lamps are operated in series on a constant-voltage circuit, prompt replacement of burnouts is desirable to protect the other lamps in the circuit which must absorb the voltage originally consumed by the burned out lamp. This type of circuit is recommended

only for 20 or more lamps, because where the number of lamps is too small excessive overvoltage is impressed on the remaining lamps when one fails. In street lighting circuits operated on constant-current transformers, the current is maintained at a fixed value regardless of the load on the line, so that failure of one lamp places no extra burden on the others. In this case a cut-out mechanism which bypasses a burned out lamp is part of the luminaire socket.

The lumen maintenance of series lamps operated at constant current is better than that of multiple lamps, for the reason that the wattage of a lamp held at constant voltage gradually *decreases* throughout life, whereas the wattage of a lamp held at constant current *increases*. This is because the resistance of the filament wire increases as its diameter decreases with evaporation. At constant *voltage* increased resistance means a decrease in amperes ($I = E/R$) and accordingly in watts. At constant *current* increased resistance results in increased voltage ($E = IR$), and a corresponding increase in watts which materially offsets the reduction in light output due to blackening.

Projector and Reflector Lamps

Projector and reflector lamps combine in one unit a light source and a highly efficient reflector consisting of a thin layer of vaporized aluminum applied to the inner surface of the bulb. The bulb walls are so shaped as to produce a concentrated beam of light whose width is controlled by the lens in the projector type, and by the frosting of the end of the bulb in the reflector type.

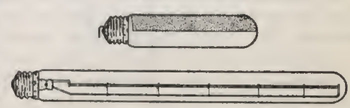
Reflector (R-40) lamps are made with blown bulbs of soft glass, and should not be exposed to rain or snow, or burned in any equipment where metal parts come in contact with the bulb. The PAR-38 bulb of the projector lamp, on the other hand, is made of molded heat resisting glass and can be used safely outdoors. Both lamps are available in the spot type, for applications where a narrow beam is necessary, or in the flood type where a wider beam is desirable.

The same principle of a sealed-in internal reflecting surface is used in the "Sealed Beam" automobile headlamp, and in several other types of PAR-bulb lamps used as spotlights, signal lamps, and airplane headlight lamps. In all of these, filaments exactly positioned in reflectors of very accurate contour give precise beam control.

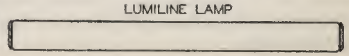
Showcase and Lumiline Lamps

Low-wattage tubular-bulb lamps are used for showcase lighting and other applications where small bulb diameter is required. Some of these are designed to be used in reflectors, and others are provided with an internal reflecting surface extending over approximately half the bulb area, which concentrates the light to form a beam. The Lumiline lamp is a special type of tubular light source which has a filament extending the length of the lamp and connected at each end to a disc base which requires a special

SHOWCASE LAMPS



LUMILINE LAMP



type of lamp holder. Lumiline lamps are considerably less efficient than conventional general lighting service lamps, but are useful where a linear source is necessary.

Spotlight, Floodlight and Projection Lamps

Characteristic features of all lamps designed for spotlight, floodlight, and projection applications are compact filaments accurately positioned with respect to the base, for purposes of light control; relatively short lives, for high efficiency and brightness; comparatively small bulbs; and restricted burning position. Since spotlight lamps must produce narrower, more intense beams than floodlight lamps, they have smaller filaments and shorter lives. In projection lamps the light source is still more concentrated and life is further reduced, with accompanying increased efficiency.

The objective in designing projection lamps is to fill the aperture of the projection system with a light source of high brightness and maximum uniformity. This is accomplished by arranging the filament coils in a single or double vertical plane, accurately located with respect to the optical system by a bayonet, prefocus, or bipost base. The biplane (C-13D) filament, with coils arranged in two parallel rows so placed that the coils of one row fill in the spaces between those of the other, has much greater uniformity and higher average brightness than the single-row monoplane (C-13) filament. Many projection lamps have such small bulbs and operate at such high temperatures that they cannot be burned without continuous forced ventilation to cool the bulb, and some have designed lives as short as ten hours. Lamps for use in certain types of projectors have an opaque black coating on the top of the bulb to prevent the emission of stray light.

Infrared Lamps

Infrared lamps are essentially the same as lamps designed for illumination purposes, the principal difference between them being that of filament temperature. Since the production of light is not an objective, infrared lamps are designed to operate at a very low temperature, resulting in the production of much less light and more infrared than lamps for lighting purposes. Actually, of course, the difference between light and infrared radiation is merely a matter of wavelength, and both of them produce heat when they are absorbed. If the absorbing surface is non-selective, the amount of heat produced per watt of incident energy is the same regardless of the wavelength. Thus ordinary lamps could be used successfully for heating and drying purposes. However, the infrared lamp has definite advantages in the reduction of glare because of its low light output (about 5 lumens per watt) and the long life resulting from its low filament temperature. Theoretically, on the basis of filament evaporation alone, the life of infrared lamps is many thousands of hours, but because of the possibility of failure from shock, vibration and other causes, the rated life is given merely as "in excess of 5000 hours."

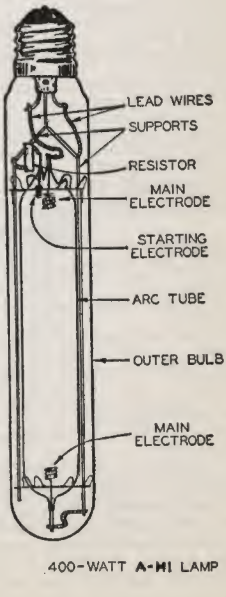
Infrared lamps used in the home and for therapeutic purposes are commonly of the convenient self-contained 250-watt R-40 bulb type with internal reflector, similar in size and appearance to the 150- and 300-watt reflector spot and flood lamps. Those used in industrial processes may be of the 250- or 375-watt reflector type, or they may be of several different wattages with clear bulbs for use in separate reflectors, usually gold-plated.

MERCURY VAPOR LAMPS

Mercury vapor lamps belong to the general classification known as *electric discharge lamps*, in which light is produced by the passage of an electric current through a vapor or gas, rather than through a tungsten wire. The application of an electrical potential ionizes the gas, and permits current to flow between two electrodes located at opposite ends of the lamp. The electrons which comprise the current stream, or "arc discharge," are accelerated to tremendous speeds. When they collide with the atoms of the gas or vapor they temporarily alter the atomic structure, and light results from the energy given off as the disturbed atoms return to their normal state. Electric discharge sources have a negative resistance characteristic, and a high-reactance transformer or some similar device must be provided to limit the current.

The three basic elements of any electric discharge lamp are the gas, the electrodes, and the bulb. In mercury vapor lamps the "gas" is vaporized mercury. Since mercury at room temperature is a liquid, seen as small drops on the inside wall of an unlighted lamp, a small amount of more readily ionized argon gas is introduced into mercury vapor lamps to facilitate starting. The original arc is struck through the ionization of this argon gas. Once the arc strikes, its heat begins to vaporize the mercury, which then gradually becomes a conductor.

The electrodes used in mercury lamps are either of the activated type, with barium oxide as the electron-emissive material coated on a coil of tungsten wire, or of the non-activated thorium metal type. The impact of the arc heats the emissive material, which supplies electrons to maintain the arc. The electrodes also act as terminals for the arc.



400-WATT A-H1 LAMP

Most mercury lamps are constructed with two bulbs, an inner bulb which contains the arc, and an outer bulb which shields the arc tube from changes in temperature and in some cases acts as a filter to remove certain wavelengths of the arc radiation. The arc-tube is made of quartz in some lamps, and of hard glass in others. The outer bulb is hard glass, the exact type depending upon the application for which the lamp is designed, and the portion of the arc spectrum which it is desired to transmit. The space between the two bulbs is evacuated in quartz-bulb lamps, and filled with inert gas where the inner bulb is glass.

MERCURY VAPOR LAMPS

TYPE	A-H4	B-H4	C-H4 (Sp) E-H4 (F1)	S-4	A-H5	C-H5
Watts (Lamp Only)①	100	100	100	100	250	250
Outer Bulb	T-10	T-16	PAR-38	A-21	T-14	T-14
Outer Bulb Glass	772	5872	772	721	774	172
Outer Bulb Finish	Clear	Nat. Red Purple	Alum. Reflect.	Clear	Clear	Clear
Arc Tube Material	Quartz	Quartz	Quartz	Quartz	Quartz	Quartz
Arc Length (In.)	1	1	1	1	1⅝	1⅝
Base	Admed. Sc.	Admed. Sc.	Admed. Sc. Skt.	Admed. Sc.	Mogul Sc.	Mogul Sc.
Initial Lumens (At 100 Hrs.)	3300	—	—	3000	10,000	10,000
Rated Average Life 5 Hours per Start 10 Hours per Start	 1000 —	 1000 —	 1000 —	 ④1000 —	 1000 —	 3000 —
Maximum Over-all Length (In.)	5⅝	5½	5 7/16	5¼	8	8
Light Center Length (In.)	3 7/16	3 7/16	—	3 7/16	5	5
Burning Position	Any	Any	Any	Any	Any	Any
Electrode Type	Thor.	Thor.	Thor.	Thor.	Thor.	Thor.
Vapor Pressure (Atmospheres)	8	8	8	8	4.5	4.5
Open-Circuit Volts	250	250	250	250	250	250
Operating Volts	130	130	130	130	135	135
Starting Current (Amperes)	1.3	1.3	1.3	1.3	2.9	2.9
Operating Current (Amperes)	0.9	0.9	0.9	0.9	2.1	2.1
Starting Time (Minutes)	3	3	3	3	4	4
Restriking Time (Minutes)	3	3	4	3	4	4
RECOMMENDED APPLICATIONS						
General Lighting	X	—	—	—	—	X
Floodlighting	—	—	X	—	—	X
Street Lighting	—	—	—	—	—	X
Black Light	X	X	X	—	X	—
Photochemical	X	—	X	X	X	—
Blueprint and Photography	X	—	—	—	X	—
Sun Lamp Service	—	—	—	X	—	—
Searchlight and Projection	X	—	—	—	—	X

① For total wattage add transformer watts which range from 8% to 25% of lamp watts depending chiefly upon the type of lamp and transformer used.

② The A-H6 is water-cooled and requires an outer water jacket, generally of quartz or 774 heat resisting glass. A similar lamp for air jet cooling is the B-H6 rated at 900 watts.

③ The A-H6, A-H9 and B-H9 are single-bulb lamps. The outer bulb is the arc tube.

④ Life of the S-4 and RS sun lamps is rated at 1000 applications in normal sun lamp use in the home, or 1000 hours at 5 hours per start.

MERCURY VAPOR LAMPS

RS	A-H1 B-H1	D-H1	E-H1	F-H1	②A-H6	A-H12	B-H12	A-H9	B-H9
275	400	400	400	400	1000	1000	1000	3000	3000
R-40	T-16	T-20	T-20	T-16	T-2	T-28	T-28	T-9½	T-9½
776	772	774	172	772	Quartz	172	774	172	973
I.F.Alum. Reflect.	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Quartz	172	Quartz	Quartz	172	③Quartz	Quartz	Quartz	③172	③973
1⅝	6	2⅜	2⅜	6	1	5	5	48	50
Med. Sc.	Mogul Sc.	Mogul Sc.	Mogul Sc.	Mog.Sc. Mech.	⅜₁₆" Sleeve	Mog.Sc. Mech.	Mog.Sc. Mech.	S/C Term.	S/C Term.
—	16,000	20,000	20,000	16,000	65,000	60,000	60,000	120,000	120,000
④1000 —	4000 6000	⑤1000 ⑤—	3000 —	4000 6000	75 —	2000 —	2000 —	4000 6000	3000 4500
6⅞	13	11	11	13	3¼	14	14	54⅞	56⅞
—	7¾	7	7	7¾	—	9	9	—	—
Any	⑥	Any	Any	⑥	Horiz.	Any	Any	Any	Any
Thor.	Oxide	Thor.	Thor.	Oxide	Mercury	Thor.	Thor.	Oxide	Thor.
1.1	1.2	2.5	2.5	1.2	110	1.5	1.5	0.4	0.4
—	220	⑦220	⑦220	220	1200	⑦220	⑦220	850	850
⑧110-125	135	135	135	135	840	135	135	535	535
3.2	4.7	4.7	4.7	4.7	2.6	12	12	9.3	9.3
2.4	3.2	3.2	3.2	3.2	1.4	8.2	8.2	6.1	6.1
2	7	4	4	7	2 Sec.	4	4	7	7
3	7	4	4	7	2 Sec.	6	6	8	8

RECOMMENDED APPLICATIONS

—	X	—	X	—	—	X	—	X	—
—	X	—	X	—	—	X	—	—	—
—	X	—	X	X	—	X	—	—	—
—	—	X	—	—	X	—	X	—	X
—	—	X	—	—	X	—	X	—	X
—	—	X	—	—	X	—	X	—	X
X	—	—	—	—	—	—	—	—	—
—	—	—	X	—	X	X	—	—	—

⑤ Rated average life at 5 hours per start for D-H1 in any position is 1000 hours. At 10 hours per start the rated average life is 3000 hours in the vertical position only.

⑥ The A-H1 and F-H1 are designed for base up burning, the B-H1 for base down burning. These types must be operated within 10° of vertical.

⑦ For normal indoor use. Higher open-circuit voltages are desirable for dependable starting at lower temperatures.

⑧ For 50-60 cycle a-c operation only. Operates directly from regular lighting circuit, no transformer required.

LAMP TYPES

Designations

The identifying designations of mercury vapor lamps are quite different from those of incandescent filament lamps. All designations contain the letter "H" (for Hg, mercury), and all types of the same wattage, which will operate on the same transformer, are given the same H-numeral designation. All "H1" lamps, for example, are 400-watt lamps requiring what is called an "H1" transformer, all "H4" lamps are 100-watt lamps operating on H4 transformers, etc. The numerals are not in order of wattage, but were merely assigned to the various lamp types in the order of their development. Specific types of lamps of a given wattage are identified by the letter preceding the H-numeral designation: A-H1, B-H1, etc. The letter designations are also assigned arbitrarily, and have no intrinsic meaning.

Radiation Characteristics

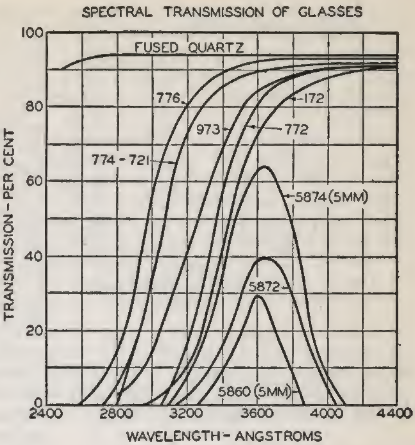
The mercury arc produces a line spectrum having strong lines in the ultraviolet and visible regions, and some in the infrared. Mercury vapor lamps vary greatly in design according to the region of the spectrum that it is desired to use. Lamps used primarily for lighting purposes are designed to produce as much energy as possible in the four important lines within the visible spectrum: 4047, 4358, 5461, and 5770-90 Angstroms. For creating fluorescence in dyes and pigments the lines in the near ultraviolet are utilized, chiefly those at 3342 and 3650 Angstroms. Erythemal (sunburn) and vitamin-D-producing or antirachitic effects are induced by shorter-wave ultraviolet radiations centering around the 2967-Angstrom line and those immediately on either side of it. The bactericidal region of the ultraviolet spectrum is of still shorter wavelengths. The 2537-Angstrom line is the effective wavelength produced by a group of special mercury vapor lamps designed for bactericidal use.

Control of the radiation generated by the mercury arc so as to produce energy in these various regions is accomplished by the choice of bulb glasses to act as filters, and to a certain extent by regulation of the vapor pressure at which the arc operates. The relative intensities of the various mercury lines change considerably with changes in vapor pressure, the general effect of increasing pressure being to shift the radiation toward the longer wavelengths, so that relatively more energy is generated in the visible spectrum and relatively less in the shortwave ultraviolet. At high pressures there is a tendency for the lines to widen, and the gaps between them to be filled in, until at 100 atmospheres the lines appear against a background of radiation that is almost continuous throughout the spectrum.

Bactericidal lamps operate at exceedingly low vapor pressures (about 10 microns) where the efficiency of production of the 2537-Angstrom line is very high. Most other types of mercury lamps are operated at medium pressures (one to ten atmospheres) where much less 2537-Angstrom energy but much more longwave ultraviolet and visible are produced.

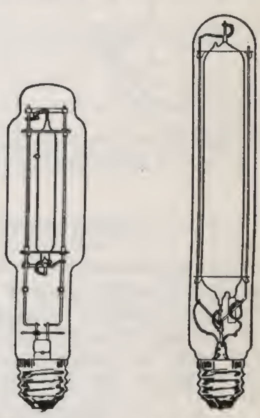
Reference to the accompanying spectral transmission curves of commonly used bulb glasses will show how the purpose for which the lamp is designed determines the choice of bulb glass for each of the lamps listed in the table of technical data.

Since quartz transmits all wavelengths equally, the outer bulb of a quartz arc-tube must be of glass that will screen out the bactericidal and erythemal ultraviolet, unless it is specifically wanted. Lamps designed for general lighting purposes have outer bulbs of 172 or 772 (Nonex) glass, which transmit very little energy below 3400 Angstroms. Lamps to be used as sources of erythemal or longwave ultraviolet energy have 774 or 776 (Pyrex) bulbs which transmit farther down into the ultraviolet, but still cut out the extremely short wavelengths that might be harmful to the eyes.



Quartz vs. Glass Inner Bulb

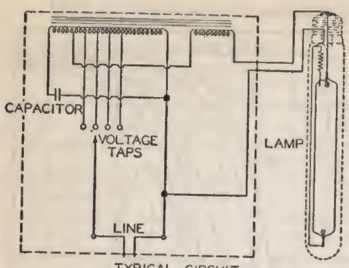
The H1 (400-watt) lamps are available with either quartz or glass arc-tubes, the choice between them being determined by the use to which the lamp is to be put. The glass arc-tube lamp has a longer rated life, but the quartz type has a 25% higher initial light output and a slightly better color quality because of the higher pressure at which its arc operates. The chief distinctions between the two types of lamps from the application standpoint, however, are the smaller light-source size and higher brilliance of the quartz-tube lamp, making it much more adaptable to applications where the light is controlled by reflector or lens systems, and its freedom from restrictions as to burning position. Glass arc-tube lamps must be burned in a vertical or nearly vertical position to prevent the arc from bowing and touching the wall of the tube, but quartz-tube lamps will give satisfactory performance in any position.



QUARTZ ARC TUBE GLASS ARC TUBE
400-WATT H1 LAMPS

AUXILIARY EQUIPMENT

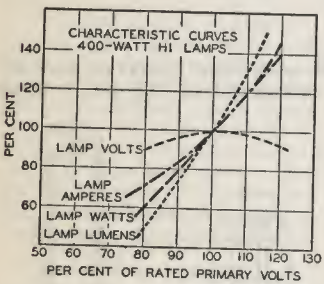
Current-limiting transformers have been designed for each type of mercury lamp to furnish proper lamp voltage and current ballasting through the inductance of the windings. The electrical characteristics of transformers when used in conjunction with discharge lamps are such as to produce a low power factor. This situation is commonly corrected by the



TYPICAL CIRCUIT
TYPE H1 HIGH REACTANCE TRANSFORMER
POWER FACTOR CORRECTED

addition of capacitance in the form of a condenser, generally built into the transformer. Uncorrected transformers have power factors of 50 to 60%, whereas the corrected ones achieve 90% or better. Two-lamp transformers only slightly larger than the single-lamp type operate one lamp on a leading current and the other on a lagging current, producing an over-all power factor of about 90%. Transformer wattage loss per lamp is in general less with the two-lamp ballast, and stroboscopic effect is greatly reduced.

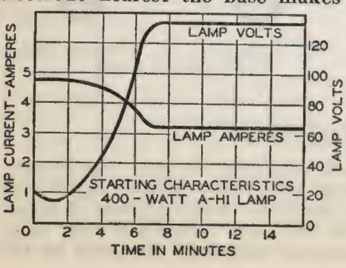
All transformers must of course be designed for the specific voltage and frequency of the supply with which they are to be used. For dependable starting and good lamp life, mercury lamps must be operated within rather narrow voltage limits, and the primary of each transformer is provided with taps for several voltages within its general range. Most equipment is designed for a frequency of 60 cycles. Operation on lower frequencies down to 25 cycles is possible, although larger transformers are required and stroboscopic effect is greater. Since the arc is actually extinguished each time the current reverses, at frequencies below 25 cycles the mercury vapor may have time between cycles to deionize and the electrodes to cool sufficiently to prevent restriking of the arc.



OPERATING CHARACTERISTICS

Starting and Restarting

The two-electrode types of mercury vapor lamps, the A-H6 and the A-H9, require starting voltages of 1200 and 850 volts to ionize the argon fill gas and permit the arc to strike. In the more common three-electrode type of lamp an auxiliary starting electrode placed close to the main electrode nearest the base makes it possible to start the lamp on 250 volts or less. Here an electrical field is first set up between the starting electrode and the adjacent main electrode, causing an emission of electrons which develops a local glow and ionizes the starting gas. The arc then starts between the main electrodes, and the mercury gradually becomes vaporized and carries an increasing portion of the current. During this process the arc stream changes from the diffuse bluish glow characteristic of

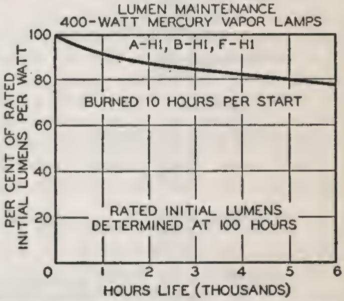


the argon arc to the blue green of mercury, increasing greatly in brilliance and becoming concentrated in the center of the tube. At the instant the arc strikes the current is high and the voltage is low. Normal operating values are reached after a warm-up period of several minutes, during which the current drops and the voltage rises until the arc attains a point of stabilization in vapor pressure.

An interruption in the power supply, or a sudden voltage drop of more than 15%, will extinguish the arc. Before the lamp will relight, it must cool sufficiently to reduce the vapor pressure to a point where the arc will restrike at the voltage available. Starting time (minutes to full light output at ordinary room temperatures with no enclosing fixture) and restriking time (cooling time until the lamp will restart) are given for the various types of lamps in the technical data table.

Lamp Life and Lumen Maintenance

The average life of general service mercury vapor lamps is relatively long. Both life and lumen maintenance are affected by the number of times the lamp is started. Each time the arc is struck some of the emission material is sputtered away and deposited on the inner surface of the arc-tube, and this process results eventually in exhaustion of the emission material and blackening of the inner bulb. Since the light output falls off rather rapidly during the first few hours of life, the rated initial lumens of mercury vapor lamps are established after 100 hours' burning. The chart shows typical lumen maintenance performance for 400-watt glass arc-tube lamps. The curve for the E-H1 quartz arc-tube lamp at 10 hours per start is similar in shape, with a value of 78% of initial lumens per watt at 70% of rated life.

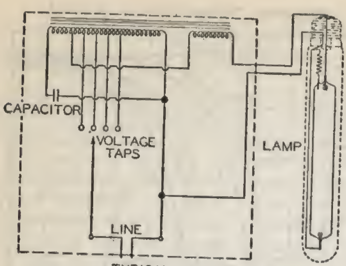


Ambient Temperature

The light ouput of the double-bulb type of mercury lamp is little affected by ambient temperature. Experience has shown that the A-H1 lamp is satisfactory for temperatures down to –20°F. The single-bulb A-H9 and B-H9 lamps, on the other hand, are rather critically affected by low temperatures, particularly if the surrounding air is moving, and are not considered suitable for use below 32°F without special protection. Ambient temperature affects the striking voltage of all discharge lamps to some extent, and higher starting voltages than those listed in the table for indoor use are recommended for street and floodlighting installations in cold climates, particularly where quartz arc-tube lamps are used.

Lamp Temperature

Because mercury vapor lamps are long-lived, operating temperatures are particularly important. The effect of heat is partly a function of time, and the longer the life of the lamp the greater the possibility of damage from high temperatures. Excessive bulb and base temperatures may cause lamp failure or unsatisfactory performance due to softening of the glass, damage to the quartz arc-tube by moisture driven out of the outer bulb, softening of the basing cement or solder, or corrosion of the base, socket, or lead-in wires. The use of any reflecting equipment that might



TYPICAL CIRCUIT
TYPE HI HIGH REACTANCE TRANSFORMER
POWER FACTOR CORRECTED

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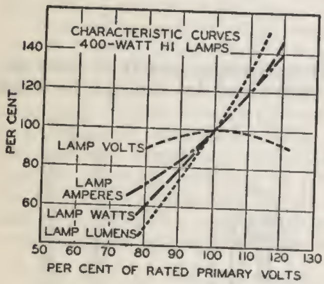

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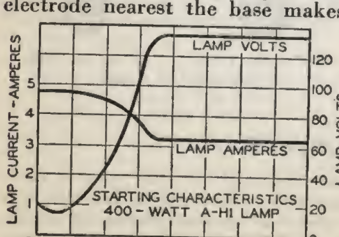

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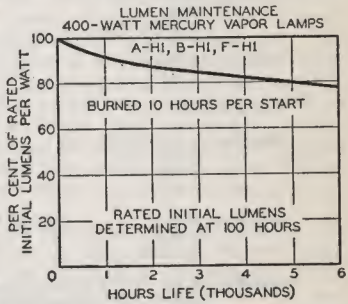

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concentrate heat and light rays on either the inner arc-tube or the outer bulb must be avoided.

The temperatures listed in the following table do not represent maximum safe operating temperatures in actual service. They are the temperatures which should not be exceeded in a laboratory test, with a new luminaire and a new lamp, operating at rated watts, and an ambient temperature of 25°C. Allowance is made for higher temperatures in service due to bulb blackening, overvoltage operation, high ambient temperatures, etc. If a lamp in a given luminaire does not exceed the rated base and bulb temperatures under laboratory conditions it should be safe in service under all ordinary circumstances.

LUMINAIRE TEST TEMPERATURE LIMITS FOR MERCURY LAMPS
(Measured at 25°C Ambient)

Lamp	Outer Bulb	*Base
100-Watt A-H4	400°C	170°C
B-H4	400°C	170°C
C-H4, E-H4	400°C	170°C
250-Watt A-H5	400°C	170°C
C-H5	475°C	170°C
275-Watt RS	250°C	170°C
400-Watt A-H1, B-H1	400°C	170°C
D-H1	400°C	170°C
E-H1	475°C	170°C
F-H1	425°C	200°C
1000-Watt A-H6	Special Cooling Required	
A-H12	475°C	200°C
B-H12	400°C	200°C
3000-Watt A-H9	375°C minimum to 550°C maximum throughout length of arc tube.	
B-H9	375°C minimum to 550°C maximum throughout length of arc tube.	

* A 10°C higher test temperature is considered acceptable in street lighting and outdoor floodlighting fixtures because the ambient temperatures during operation are generally lower than in other types of service.

Two lamps, the A-H6 and B-H6, have so much wattage condensed into so small a space that they require forced cooling. The A-H6 operates in a water jacket with a continuous stream of water flowing through it, and the B-H6 is designed to be cooled by two high-pressure air jets directed at the bulb, one opposite each electrode.

APPLICATION INFORMATION

Color

The line spectrum of mercury lamps is a very efficient source of light, but its deficiency in the red and preponderance of blue and green results in marked distortion of object colors, and makes its use undesirable where the appearance of colors is important. Color correction satisfactory for many purposes may be obtained by adding tungsten filament lamps in the same fixture or alternate fixtures, to supply the red lacking in the mercury spectrum. The incandescent lamps also furnish light while the mercury lamps are heating up. The minimum amount of incandescent light necessary to provide noticeable color improvement, particularly in the appearance of the human skin, is about 15% of the total light, on the basis of lumens. Beyond a ratio of approximately 60% incandescent lumens to 40% mercury lumens the additional improvement obtained by

adding more incandescent lamps is slight, and the over-all efficiency of the lighting system is seriously reduced. The distinctive color of mercury light may sometimes be an advantage, as in certain street lighting applications, or in floodlighting designed to attract attention to roadside stands, service stations, or displays.

Stroboscopic Effect

The arc of a mercury vapor lamp operating on 60-cycle alternating current is completely extinguished 120 times a second. Thus there is a tendency for the eye to see in flashes, with the result that a rapidly moving object may appear to move in a series of jerks. Stroboscopic effect may be greatly reduced by operating pairs of lamps on lead-lag two-lamp transformers, or three lamps on the separate phases of a three-phase supply. The use of incandescent lamps in combination with mercury lamps also lessens stroboscopic effect.

Lamp Applications

Mercury lamps are most commonly used for general lighting purposes in high bay installations covering large areas, as in steel mills, airplane plants, and foundries, where color discrimination is not important. The technical data table gives some indication of the many special uses in addition to general lighting for which mercury lamps are particularly well adapted. The development of the quartz arc-tube lamp, with its universal burning position and smaller source size, has made possible a greatly increased use of mercury lamps in floodlighting and street lighting. The high source brightness of mercury lamps gives them limited applications in certain projection systems where a complete color spectrum is not necessary.

The ultraviolet portion of the mercury spectrum is effective in a wide range of photochemical applications such as blueprinting, photocopying, bleaching, and chlorination. Mercury lamps of medium pressure, especially those of the quartz type, are highly efficient sources of the near ultraviolet energy used for the activation of fluorescent and phosphorescent dyes and pigments and the creation of "black light" effects. The RS and S-4 sun lamps generate erythemal ultraviolet at effective intensities, the RS lamp being a self-contained unit requiring no auxiliary equipment.

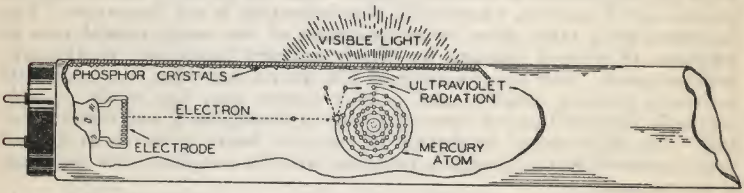
SODIUM VAPOR LAMPS

Sodium vapor lamps are similar to mercury lamps in general principle, except that the arc is carried through vaporized sodium, and the starting gas is neon. The vapor pressure at which the sodium arc operates is low, and the arc-tube must be enclosed in a vacuum flask to maintain the proper operating temperature. The starting time to full light output is 15 to 20 minutes, but the lamp will restart immediately after interruption of the power supply. The light produced by the sodium arc is almost monochromatic, consisting merely of a double line in the yellow region of the spectrum at 5890-96 Angstroms. Because all the energy emitted is so near the maximum of the eye sensitivity curve, efficiencies as high as 55 lumens per watt are obtained. The disadvantage of the limited spectrum is that all objects appear as yellow, or shades of yellow, and this characteristic restricts the use of sodium lamps to certain types of outdoor lighting. In addition, the large size and low brightness of the arc make accurate light control rather difficult. Sodium lamps find their chief application in street and highway lighting, particularly at intersections and other locations where a distinctive color is desirable.

FLUORESCENT LAMPS

THEORY OF OPERATION

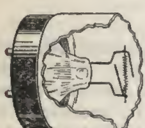
The fluorescent lamp is essentially an electric discharge source. It consists of a tubular bulb having electrodes sealed into each end and containing mercury vapor at low pressure with a small amount of argon (for starting). The inner walls of the bulb are coated with fluorescent powders which give off light when activated by ultraviolet energy. When the proper voltage is impressed on the electrodes, a flow of electrons is driven from one electrode and attracted or pulled to the other. As these electrons speed through the tube they collide with the mercury atoms, causing a state of excitation which produces shortwave ultraviolet radiation (2537 Angstroms). The fluorescent powders, commonly known as phosphors, absorb this invisible energy and radiate visible light.



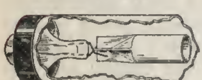
LAMP CONSTRUCTION

Cathodes

Two principal types of electrodes are employed in fluorescent lamps, the coated coiled coil tungsten wire and the inside-coated cylindrical metal tube.



HOT CATHODE



COLD CATHODE

The coiled tungsten wire type of electrode is coated with an emission material of barium and strontium oxide which when heated gives off electrons. The process is called thermionic emission because the electrons are emitted more as a result of the heat developed than of the voltage applied. A hot spot is created on the cathode at the point where the mercury arc strikes, and a continuous stream of electrons is produced. This type of operation is characteristic of what is known as the "hot cathode" lamp. As originally developed it required a preheating of the cathodes to produce the necessary electrons to strike the arc. By the use of a higher impressed voltage it can also be made to start instantly, without preheating.

The coated iron cylindrical-tube electrode commonly known as the "cold cathode" also relies on the application of a high voltage to pull electrons from the unheated cathode and provide instant starting. The arc

terminates on the entire cylinder, instead of at a particular point, as on the coiled wire or hot cathode. Thus the heat is generated over a larger area and the cathode does not reach as high a temperature at any one place; hence the name "cold cathode." Because of the lower temperature and the lack of thermionic emission a higher voltage is necessary to maintain the electron supply. The potential drop at a cold cathode is about five times that at a hot cathode, and consequently the cathode wattage loss is much greater and the lamp is less efficient. The cold cathode does, however, have a longer life, especially where the lamp is subjected to frequent starting, as on flashing circuits.

Phosphors

The fluorescent and phosphorescent materials most commonly used in paints, dyes and plastics are excited by longwave ultraviolet in the neighborhood of 3650 Angstroms. Fluorescent lamps employ compounds of another type activated by 2537-Angstrom ultraviolet, which is the wavelength most efficiently generated by a low-pressure mercury arc. The phosphors selected for use in lamps are chosen because they are efficient converters of this shortwave energy into light, and because they are stable compounds which maintain their light output at a reasonable level throughout the life of the lamp.

The color produced depends on the chemical composition of the phosphors. The White, 4500 White, Daylight and Soft White lamp colors are obtained by the mixing of phosphors in various proportions. Green, Blue and Pink lamps use single phosphors, while Gold and Red lamps use a phosphor plus a colored coating applied to the inner surface of the bulb.

Phosphor	Color of Fluorescence
Zinc Silicate	Green
Calcium Tungstate	Blue
Cadmium Borate	Pink
Zinc Beryllium Silicate	Yellowish White
Magnesium Tungstate	Bluish White

Another phosphor known as 360BL is an efficient source of near ultraviolet, with its maximum energy output at about 3650 Angstroms. Lamps made with this phosphor produce very little visible radiation, and are intended for use only in activating fluorescent and phosphorescent materials. In other respects 360BL lamps are similar to standard fluorescent lamps.

Lamp Types

Fluorescent lamps, commonly designated as "*Type F*" lamps, are made with tubular bulbs varying in diameter from T-5 (5/8 inch) to T-17 (2 1/8 inches). The standard line of lamps with preheat cathodes vary in length from 9 inches to 60 inches. Slimline lamps are made in T-6 and T-8 bulbs, and range up to 96 inches in length. They employ the instant-start type of hot cathode.

The 40-watt T-12 lamp is available with either the preheat or the instant-start cathode. Fluorescent lamps are also made in the form of a circle. These are known as Circline lamps, and they have the preheat type of cathode.

REFERENCE DATA ON FLUORESCENT LAMPS
(For Life See Rated Life Table)

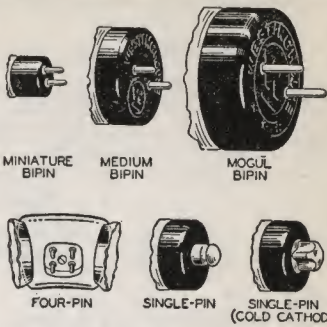
①Lamp	Base	Approx. Operating Amps.	Approx. Operating Volts	② Open Circuit Volts	③ Preheat Amperes	⑤Rated Initial Lumens ④ White	4500 White	Daylight
6-W 9" T-5	Min. Bipin	0.145	47	118	0.18	210	198	186
8-W 12" T-5	Min. Bipin	0.165	55	118	0.21	330	310	295
13-W 21" T-5	Min. Bipin	0.160	95	200	0.20	585	545	520
14-W 15" T-12	Med. Bipin	0.370	41	118	0.55	490	460	435
⑥15-W 18" T-8	Med. Bipin	0.300	56	118	0.55	615	600	585
15-W 18" T-12	Med. Bipin	0.330	48	118	0.55	600	570	540
⑥20-W 24" T-12	Med. Bipin	0.360	60	118	0.55	920	860	800
⑥30-W 36" T-8	Med. Bipin	0.340	103	200	0.53	1470	1380	1350
⑨⑥40-W 48" T-12	Med. Bipin	0.415	106	200	0.65	2320	2100	1920
100-W 60" T-17	Mog. Bipin	1.450	72	150	1.78	4200	4000	3900
Instant-Start								
40-W 48" T-12	⑦Med. Bipin	0.415	106	450	....	2320	2100	1920
40-W 60" T-17	⑦Mog. Bipin	0.400	110	450	....	....	2100	....
⑧Slimline								
16-W		0.100	180	450	....	930	880	....
25-W 42" T-6	Single-Pin	0.200	150	450	....	1400	1320	....
33-W		0.300	130	450	....	⑩	1620	....
24-W		0.100	285	600	....	1440	1370	....
39-W 64" T-6	Single-Pin	0.200	230	600	....	2250	2150	....
51-W		0.300	200	600	....	⑩	2600	....
22-W		0.100	250	600	....	1410	1340	....
38-W 72" T-8	Single-Pin	0.200	220	600	....	2350	2250	....
51-W		0.300	200	600	....	⑩	2850	....
29-W		0.100	335	750	....	1890	1800	....
51-W 96" T-8	Single-Pin	0.200	295	750	....	3200	3050	....
69-W		0.300	265	750	....	⑩	3950	....
Circline								
32-W 12" Diam. T-10	Four-Pin	0.430	84	150	0.65	1600	....	....

① Lamp watts, nominal over-all length (one lamp plus two standard lampholders), and bulb designation (T for tubular; number indicates tube diameter in eighths of an inch).
② Minimum open-circuit volts at rated line voltage of ballast.
③ Center value.
④ Soft White lamps have lumen outputs approximately 25% less than the corresponding White lamps.
⑤ Lumens when measured at 80°F ambient, and under specified test conditions. The light output of a new lamp will appreciably exceed the above rated initial values, which apply when the lamps have burned 100 hours.
⑥ Regularly available also in Blue, Green, Gold, Pink, and Red.
⑦ Base pins shorted inside base.
⑧ Slimline lamps may be operated at any intermediate value between 100 and 300 milliamperes. The light output increases with the current loading. For example, the lumen and wattage values of the 96" T-8 lamp are approximately 16 and 40% higher at 120 and 150 milliamperes, respectively, than at 100 milliamperes.
⑨ A Low Temperature 40-watt T-12 lamp, marked with the letters "LT," gives reliable starting down to 0°F.
⑩ The lumen output is about 5% above that of the 4500 White lamp.

Bases

Lamps incorporating preheat cathodes require four electrical contacts, which in the standard line of lamps take the form of a bipin base at either end. There are three standard types of bipin bases: miniature bipin, medium bipin, and mogul bipin. In Circline lamps the contacts are brought together in a four-pin base located between the two cathodes where the ends of the lamp adjoin.

Lamps of the instant-start type require only two contacts, Slimline lamps having single-pin bases. The 40-watt Instant-Start hot cathode lamp has the medium bipin base, but contains an electrical bridging member between the pair of contacts at each end, producing in effect a single contact for each cathode. Because of this construction, these lamps cannot be operated in circuits containing starters. Cold cathode lamps are also instant-start lamps and have a single contact at each end, usually in the form of a cap base or a Slimline base with a "clover leaf" terminal.



AUXILIARY EQUIPMENT

Like all electric discharge lamps, fluorescent lamps must have an auxiliary, commonly known as a ballast, to limit the current and in most cases to provide the necessary starting voltage. Each lamp requires a ballast specifically designed for its characteristics, and for the service voltage on which it is to be operated. The chief differences among ballasts lie in the range of open-circuit voltages supplied to the lamp. Lamps with preheat cathodes require relatively low starting voltages, not over 200 volts, hot cathode instant-start and most multiple cold cathode lamps from 450 to 750 volts, and cold cathode lamps operated in series, considerably higher voltages.

Preheat Ballasts

The preheat type of ballast serves three important functions:

1. Preheats the electrodes to make available a large supply of free electrons.

2. Provides a surge of sufficiently high potential to start the arc.

3. Prevents the arc current from increasing beyond the limit set for a particular size of lamp.

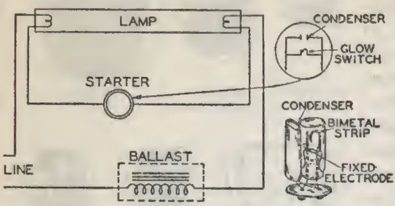
Preheat ballasts are either simple chokes or chokes plus autotransformers, depending on the length of the lamp and the supply voltage. When the starting voltage required is not greater than the supply voltage the ballast is a choke which merely limits the current flow. When the supply voltage is not sufficient to start the arc the ballast includes both a step-up autotransformer to provide the necessary starting potential, and a choke to limit the current.

Starters

The preheat type of lamp requires a temporary starting circuit through the cathodes. The duration of this flow of current may be controlled manually, but most installations contain automatic switches. Starting switches may be of the thermal- or the glow-switch type, the latter being in much more common use today.

The glow-type starting switch consists of two electrodes, one of which is a bimetallic strip, enclosed in a small glass bulb filled with an inert gas such as neon or argon. When voltage is applied a small current flows through the circuit as a result of a glow discharge between the two electrodes of the switch. The heating effect of the current expands the bimetallic element and causes the electrodes to touch. The closing of the switch stops the glow discharge, but allows a substantial flow of current to preheat the lamp electrodes during the short period of time when there is enough residual heat in the switch to keep it closed. As the bimetal cools the switch opens, and the resultant high-voltage surge starts normal lamp operation. If the lamp arc fails to strike, the cycle is repeated.

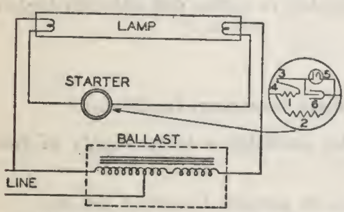
GLOW-SWITCH STARTER



The switch does not glow after the lamp arc is established, since it is so designed that the remaining available electrical potential is insufficient to cause a breakdown between its electrodes. Thus it consumes no power, and when the lamp is turned off is available for immediate restarting.

The conventional starter consists of the glow switch plus a condenser to suppress radio interference, both enclosed in a small cylindrical container which is inserted in a two-contact bayonet-type socket. Since the glow switch is designed to operate between critical voltage limits, the proper starter must be used for each type of lamp.

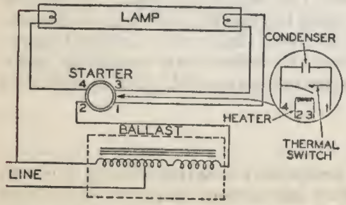
NO-BLINK STARTER



1-LOW RESISTANCE HEATER 4-BIMETAL STRIP
2-HIGH RESISTANCE HEATER 5-GLOW SWITCH
3-LOCK-OUT CONTACT 6-CONDENSER

The No-Blink starter contains a regular glow switch plus an additional bimetallic element which automatically cuts the lamp out of the circuit after several unsuccessful attempts to start. Its use prevents annoying blinking of lamps which have reached the end of life, and protects the ballast against continuous flow of the high preheat current.

THERMAL STARTER



The thermal starter consists of a heater coil which operates a bimetallic switch, in a small container requiring a four-contact bayonet-type socket. The coil must remain in the circuit to keep the switch open while the lamp is in operation, and a thermal starter therefore consumes a small amount of current. Starters of this kind are recommended for d-c operation and for low-temperature starting, where glow switches are less likely to give satisfactory service.

***REFERENCE DATA ON FLUORESCENT LAMP BALLASTS**
APPROXIMATE WATTS LOSS PER LAMP

Lamp	Starter Switch Number	110-125 Volts			②220-250 Volts		
		Single-Lamp		Two-Lamp	Single-Lamp		Two-Lamp
		①Low PF	①High PF	①High PF	①Low PF	①High PF	①High PF
6-W 9" T-5	FS-5	2	....	....	....	....	....
8-W 12" T-5	FS-5	2.8	....	....	....	....	....
13-W 21" T-5	FS-4	7	6	....	....	....	....
14-W 15" T-12	FS-2	3.6	3.6	③	....	....	....
15-W 18" T-8 / 15-W 18" T-12	FS-2	4.5	4.5	4.5	....	....	....
20-W 24" T-12	FS-2	4.5	4.5	4.5	....	....	....
30-W 36" T-8	FS-4	10	10	7.25	9	9	6.25
④40-W 48" T-12	FS-4	13	15	8.75	12	13	7.25
100-W 60" T-17	FS-6	....	24	17.5	....	24	17.5
Instant-Start							
40-W 48" T-12 / 40-W 60" T-17	Instant-Start	....	....	14	....	....	12.5
Slimline							
16-W 42" T-6	Instant-Start	11	10	5.75	....	....	....
25-W 42" T-6		15.5	17	9	....	....	....
24-W 64" T-6		12.5	10	7.5	....	....	....
39-W 64" T-6		22	17	12	....	....	....
22-W 72" T-8		12.5	10	7.5	....	....	....
38-W 72" T-8		22	17	12	....	....	....
29-W 96" T-8		....	11.5	8	....	....	....
51-W 96" T-8		....	19.5	14	....	....	....
Circline							
32-W 12" Diam. T-10	Manual or Glow Switch	11.5	9	8	....	....	....

*The wattage losses shown are for standard case type ballasts designed for operation on 60-cycle service. The long, narrow type of ballast usually has a slightly higher wattage loss. For exact figures, manufacturers' catalogues should be consulted.

Information on auxiliary equipment for use with direct current is included in the section on Direct-Current Operation.

① Low power factor ballasts have power factors ranging from about 45 to 60%; high power factor ballasts have power factors of 90% and over.

② Ballasts for the 199 to 216-volt range have approximately the same wattage loss.

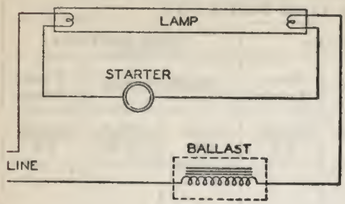
③ Two 14-watt lamps may be operated in series with a 60-volt 0.5-ampere S-11 resistance ballast lamp. A manual starter is required, and the ballast loss is 7.5 watts per lamp. This circuit is suitable for either alternating current (power factor 95 to 100%) or direct current.

④ Three-lamp high power factor ballasts for 40-watt lamps are available for the 110 to 125-volt range (wattage loss 8 watts per lamp), and the 220 to 250-volt range (wattage loss 7.66 watts per lamp).

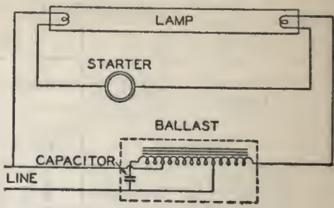
Multi-Lamp Ballasts

Hot cathode lamps may be operated on single- or multi-lamp ballasts. Uncorrected single-lamp ballasts, whether simple choke coils or autotransformers, have low power factors of about 45 to 60%. High power factor single-lamp auxiliaries are available, or separate capacitors may be used with low power factor equipment.

SINGLE-LAMP SIMPLE CHOKE BALLAST
LOW POWER FACTOR

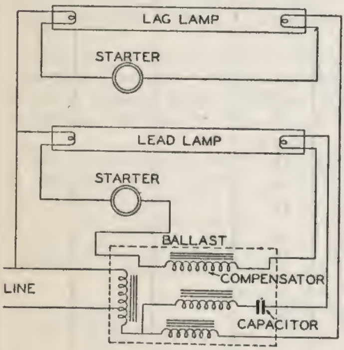


SINGLE-LAMP AUTOTRANSFORMER BALLAST
POWER FACTOR CORRECTED



In a two-lamp ballast each lamp has a separate reactor, with a capacitor connected in series with one of the reactors to produce a leading current in one lamp. Such a ballast has the advantage of providing high power factor (between 90 and 100%) and decreased stroboscopic effect, with reduced auxiliary wattage loss and lower ballast cost per lamp. Since the currents of the two lamps are approximately 115° out of phase, the fluctuations in light output do not occur simultaneously, and stroboscopic effect is considerably reduced.

TWO-LAMP PREHEAT CIRCUIT

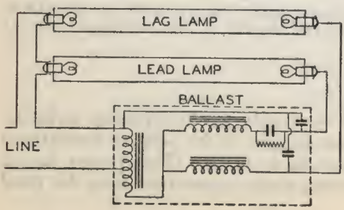


Multi-lamp ballasts for 15- to 40-watt standard lamps require an inductive compensator in order to provide the proper preheat current for the lead lamp. This compensator is connected in series with the starting switch of the lead lamp, and functions only when the lamp is starting, being cut out of the circuit when the starting switch opens. Starting compensators are built into most multi-lamp ballasts for these lamp sizes. Where they are not a part of the ballast they should be added to the circuit to facilitate starting and to insure normal life for the lead lamp. They are not required with 100-watt, Instant-Start, or Slimline lamps.

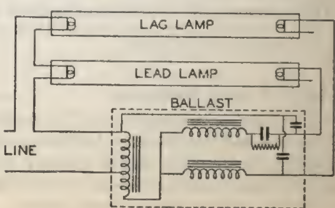
Instant-Start Ballasts

Instant-Start and Slimline ballasts perform only two of the three functions served by preheat ballasts: they provide the necessary potential to

TWO-LAMP SLIMLINE CIRCUIT



TWO-LAMP INSTANT-START CIRCUIT



start the lamp, and they limit the arc current. Because of the higher voltages involved, these ballasts are larger than those for starter operation, and the ballast losses are somewhat greater. Slimline ballasts are generally designed for a lamp current of 100, 200, or 300 milliamperes. Like the preheat type of ballast, they are available for single- and for two-lamp operation.

Frequency

The current-limiting characteristics of a ballast depend directly on the frequency of the power supply, and for this reason ballasts must be used on the frequency for which they were designed. When a single-lamp ballast is used on a frequency lower than design, the inductive reactance is reduced and excessive current flows through the lamp. Shorter lamp life and overheated auxiliaries result. With a two-lamp ballast the current in the lagging leg is similarly increased, but at the same time the current in the leading leg is reduced, due to its capacitive reactance, with resultant adverse effects on lamp life and light output. Operation on higher than rated frequencies will have opposite effects on the currents in the circuits.

Operation at low frequencies, such as 25 cycles, requires a larger ballast which is less efficient, and in addition results in more pronounced stroboscopic effect. Higher frequencies, such as 400 cycles, have been used satisfactorily on airplanes with special auxiliaries designed for the application.

OPERATING CHARACTERISTICS

Lamp Life

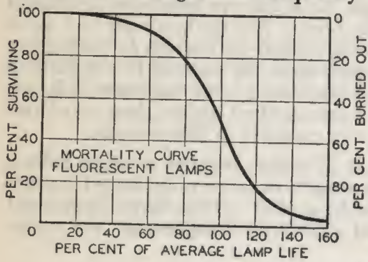
The life of a fluorescent lamp is affected not only by the voltage and current supplied to it, but also by the number of times it is started. Electron emission material is "sputtered off" from the electrodes continuously during the operation of the lamp, and in particularly large quantities each time the lamp starts. Since the normal end of life is reached when

RATED AVERAGE LIFE OF FLUORESCENT LAMPS IN HOURS

Lamp	Burning Hours per Start		
	3	6	12
6-W 9″ T-5	2500	....	....
8-W 12″ T-5	2500	....	....
13-W 21″ T-5	2500	....	....
14-W 15″ T-12	2500	....	....
15-W 18″ T-8	2500	4000	6000
15-W 18″ T-12	2500	4000	6000
20-W 24″ T-12	2500	4000	6000
30-W 36″ T-8	2500	4000	6000
40-W 48″ T-12	2500	4000	6000
40-W 48″ T-12 Low Temp.	1500	....	....
100-W 60″ T-17	3000	4500	6500
Instant-Start			
40-W 48″ T-12	2500	4000	6000
40-W 60″ T-17	2500	....	....
Slimline (All Types)	2500	4000	6000
Circline			
32-W 12″ Diam. T-10	2500	....	....

the emission material is completely consumed from one of the electrodes, the greater the number of burning hours per start the longer the life of the lamp. When the emission material is exhausted, lamps on a preheat type of circuit will blink on and off as the electrodes heat but the arc fails to strike. Lamps designed for instant starting will simply fail to operate. Blinking lamps should be removed from the circuit promptly, to protect both the starter and the ballast from overheating.

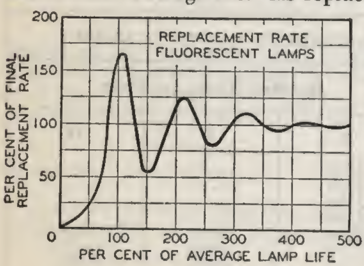
The rated average life of a fluorescent lamp in burning hours is based upon the average life of large representative groups of lamps tested in the laboratory under controlled conditions. Ordinarily, with suitable auxiliaries, line voltage, and frequency this average life will be obtained in service. When a large group of lamps is tested it will be found that failures occur very nearly in accordance with the mortality curve shown here, the average life being the point at which approximately 50% of the lamps have burned out.



In any installation large enough so that the laws of random sampling apply, the average number of failures for a given period can be estimated from the formula:

$$\text{Number of failures per month} = \frac{\text{Hours burned per month x Number of lamps}}{\text{Lamp life}}$$

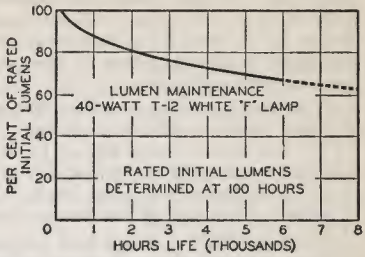
This relationship can be applied only after an installation has been in service for some time, and the renewal rate has reached an equilibrium. A theoretical replacement curve calculated for an installation of new lamps shows a maximum number of renewals as the initial lamps approach the end of their average life. As replacements gradually become mixed with the original group, fewer of the lamps reach the end of life at each succeeding multiple of the average life, and the curve flattens out. A constant renewal rate cannot be expected until an installation has been in operation for a number of burning hours equal to five or six times the rated life of the lamps. Because of the long life of the fluorescent lamp, the fluctuation in replacement rate may continue over a period of several years.



Lumen Maintenance

The light output of a new fluorescent lamp drops off about 10% during the first 100 hours of burning. Since the depreciation after this initial drop is much more gradual, fluorescent lamps are rated at the end of this period. The published "initial lumens" for a fluorescent lamp is the value obtained after 100 hours' burning. Under favorable operating conditions, and on the basis of three hours' burning per start, the light output during life averages approximately 80 to 85% of the 100-hour value. The typical lumen maintenance curve illustrated here represents the average per-

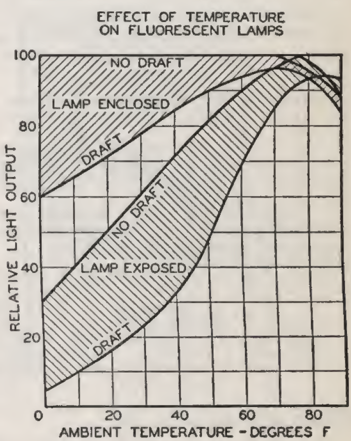
formance of a large number of lamps of one type. Individual lamps vary somewhat both in lumen maintenance and in length of life, and the longer the life the greater the drop in light output. In installations where the lamps are operated continuously some lamps may burn as long as 10,000 hours, but their depreciated light output will generally make it uneconomical to use them much beyond 6000 hours.



The depreciation in light output is due chiefly to a gradual deterioration of the phosphor powders, and a blackening of the inside of the tube. The blackening is produced by electrode material deposited on the inner surface of the bulb, and is therefore more pronounced at the ends of the lamp. The smaller the lamp diameter and the closer the electrodes to the bulb wall, the greater the darkening. In the last few hours of lamp life a rather dense deposit develops at the end of the lamp where the electrode is deactivated. This effect is especially marked if the lamp is allowed to flash on and off before it is replaced.

Effect of Temperature

Fluorescent lamps are designed to operate at rated values at ordinary indoor temperatures, and either low or high ambient temperatures will have some effect on their operating characteristics. Lumen output varies with the temperature of the bulb wall, which of course is affected by the temperature and movement of the surrounding air. Rated lumen values are based on measurements made at 80°F ambient temperature in still air with bulb-wall temperatures of 100 to 120°F. Light output decreases about 1% for each one-degree drop in bulb temperature below this range, and a like amount for each three-degree increase up to 200°F. This variation in lumen output is due largely to a change in the character of the arc discharge, which alters the relative amount of ultraviolet generated and thereby affects the subsequent production of light by the phosphor. Luminaires are usually designed to make provision for these temperature characteristics of the lamp.



In addition to a decrease in light output, low temperature may also cause lamps operated by glow-switch starters to flash on and off. This effect is the result of a rise in the voltage across the lamp, which accompanies a decrease in temperature. If the voltage becomes sufficiently high to activate the glow switch, the starter circuit will repeatedly go through its operating cycle, intermittently extinguishing the lamp. Thermal starters, which are independent of variation in arc voltage, should be used for

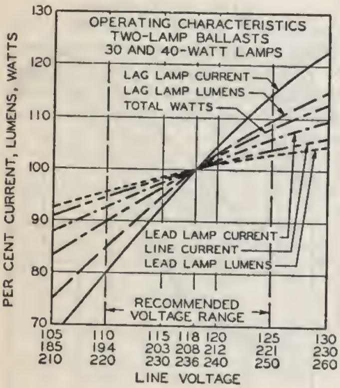
satisfactory operation at low temperatures. Standard lamps, if protected from drafts and provided with thermal or manual starting switches, and with line voltages above the optimum voltage for normal temperatures (118, 208, or 236 volts), can be operated at temperatures as low as 32°F. Below 32°F, special low-temperature lamps or fixtures embodying heating elements (filament lamps or heater coils) in addition to the above precautions are required.

A special Low Temperature 40-watt T-12 lamp which will give reliable starting down to 0°F is available. This lamp is marked with the letters "LT" and has a rated life of 1500 hours. The standard 100-watt lamp will also start satisfactorily down to 0°F. However, all fluorescent lamps must be enclosed to protect them from drafts if a reasonable light output is to be maintained at low temperatures.

Because Slimline lamps and Instant-Start 40-watt T-12 lamps operate without starters, there is no recycling of starter switches at low temperatures. Also the higher voltages provided by their ballasts reduce the likelihood of the lamps being extinguished by cold. Once they are started at low temperatures, they will stay lighted. However, starterless systems do not have the advantages of the electrode preheat and the starting voltage surge provided by the breaking of the starter circuit, and at very low temperatures the arc may fail to strike.

Effect of Voltage

The voltage at the luminaire should be kept well within the norma operating range for the ballast. Low voltage, as well as high voltage, reduces efficiency and shortens lamp life. This is in contrast with filament lamps, where low voltage reduces efficiency but prolongs life. Low voltage may also cause instability in the arc, and starting difficulty.



On voltages above the specified range, the operating current becomes excessive and may not only overheat the ballast but cause premature end-blackening and early lamp failure. Voltages below the specified range may lower the preheat current to a point where the electrodes fail to emit their proper quota of electrons. Such a condition may cause the lamps to flash on and off without starting. If the lamps do start, the emission material may waste away too rapidly, with consequent shortening of lamp life.

Effect of Humidity

The electrostatic charge on the outside of a fluorescent lamp bulb affects the voltage required to strike the arc. Moist, humid air surrounding the lamp affects this surface charge unfavorably, requiring much higher starting voltages when the instant-start type of ballast is used. When the relative humidity exceeds 65% this becomes an important factor, and its effect increases rapidly as the humidity approaches 100%.

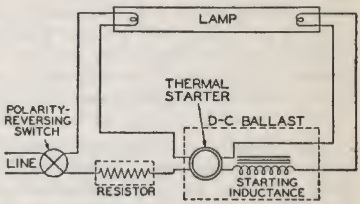
Slimline lamps are equipped with a thin "starting stripe" of silver ink, extending practically the full length of the outside of the bulb. This

device makes possible dependable starting at normal voltages, under any condition of humidity. Instant-Start 40-watt lamps are also available with a similar starting stripe for high-humidity conditions.

Direct-Current Operation

Although the fluorescent lamp is basically an a-c lamp, it is adaptable to operation on direct current provided sufficiently high voltage is available, and the proper auxiliary equipment is used. An external resistance in series with the lamp controls the current. Because of the lack of a voltage peak, lamp starting on direct current is more difficult than on alternating current, and special starting devices such as thermal-type or manual switches, plus starting inductances, are necessary. Although total light output on direct current is comparable to that obtained on alternating current, the greater wattage loss in the resistance reduces the over-all lumens per watt efficiency of the d-c system to about 60% of that of the a-c system. Lamp life is also adversely affected by d-c operation, and lamps can be expected to give only about 80% of their normal life.

CIRCUIT FOR DIRECT-CURRENT OPERATION



The steady flow of direct current in one direction forces the mercury molecules to one end of the tube, resulting in inadequate generation of the ultraviolet energy required for the fluorescence of the phosphors at the other end. Thus after a few hours' operation on direct current one end of the lamp may become dim. It is recommended that polarity-reversing switches be installed in d-c circuits so that the direction of the current flow can be reversed when necessary.

The accompanying table gives data on the d-c operation of fluorescent

AUXILIARY EQUIPMENT FOR DIRECT-CURRENT OPERATION

Lamp	D-C Lamp Current (Amperes)	*External Resistance Required (Ohms)		Auxiliary Watts Loss per Lamp (Resistance plus Inductance)
		120 Volts	240 Volts	
6-W 9″ T-5	0.125	551	...	9
8-W 12″ T-5	0.14	425	...	9
**14-W 15″ T-12	0.34	204	...	24
15-W 18″ T-8	0.26	210	...	16
15-W 18″ T-12	0.29	206	...	20
20-W 24″ T-12	0.31	149	...	17
30-W 36″ T-8	0.29	...	444	40
40-W 48″ T-12	0.35	...	335	44
100-W 60″ T-17	1.27	...	124	204
Circline 32-W 12″ Diam.T-10	0.37	...	391	57

* These values of resistance must be used in series with the d-c starting inductance (ballast) to provide the proper lamp current. This resistance is in addition to the internal resistance of the starting inductance. Resistors must be capable of carrying the lamp current without overheating, and should be within about 10% of the values shown.

** Two 14-watt lamps may be operated in series with a 60-volt 0.5-ampere S-11 resistance ballast lamp. The auxiliary wattage loss is 7.5 watts per lamp.

lamps, including the amount of resistance which must be used with the inductance, and the total wattage loss in the auxiliary equipment. Because lamps of 30 watts and larger require over 120 volts for starting, they must be operated on circuits in the 240-volt range or higher. Slimline and Instant-Start lamps require higher starting voltages than are provided by any standard d-c circuit.

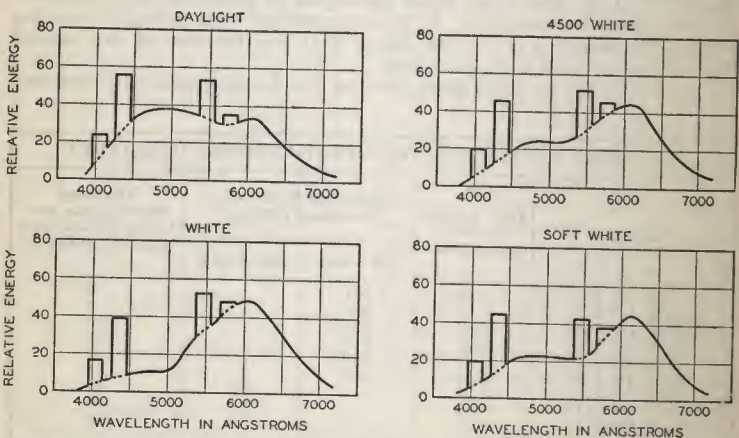
APPLICATION INFORMATION

Color

The spectral energy distribution curve of a fluorescent lamp shows a continuous spectrum for the radiation produced by the phosphor plus lines representing a small portion of the radiation from the mercury arc that is not absorbed by the phosphor. Actually the mercury lines are monochromatic, and very strong in intensity for an exceedingly narrow width. As plotted here they are represented by blocks 200 Angstroms wide, with the height chosen so that the area of the block represents the total amount of energy in the spectral line.

The Daylight fluorescent lamp is an approximate duplication of the color of average noon daylight in Washington, D. C. This lamp is particularly suitable for daylight effects, and for color discrimination or color comparison processes where the requirements are not too exacting. While no fluorescent lamp is an exact color match for a blackbody, the color of the Daylight lamp is sufficiently close to that of a blackbody at 6500°K to be described as having a color temperature of 6500°K.

SPECTRAL ENERGY DISTRIBUTION FOR FLUORESCENT LAMPS

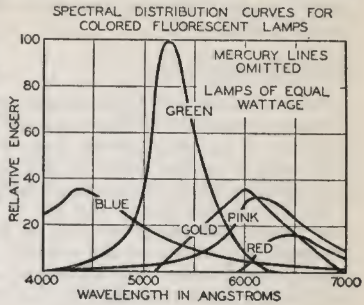


The standard White lamp has a color temperature of approximately 3500°K, which is slightly above the highest practical temperature for tungsten filament lamps. Because of its similarity to the color of the filament lamp, to which people have become accustomed, and because it is the most efficient of the four "whites," it is widely used for general-area lighting.

The 4500 White lamp is about halfway between standard White and

Daylight, in color and in efficiency. It is better suited than the White lamp for mixing with natural illumination, and creates a slightly less "cool" atmosphere than the Daylight lamp. The Soft White lamp is considerably pinker than the other "whites." Although 25% less efficient than the standard White, it has found many uses where the warmer, more flattering, tones are desired, as for example in restaurants and in residential lighting.

Blue, Green, Gold, Pink, and Red fluorescent lamps, in the standard 15 to 40-watt sizes, produce colored light at high efficiencies for signs and decorative applications.



Brightness

Since the light of a fluorescent lamp is generated over a large surface area, its brightness is comparatively low. Thus where fluorescent lamps are used in direct-lighting luminaires the reflected glare from specular objects is much less than that produced by the more concentrated filament

BRIGHTNESSES OF FLUORESCENT LAMPS

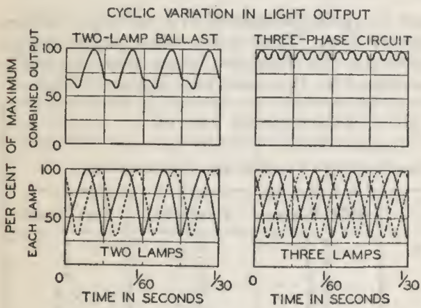
Lamp	Approximate Candles per Square Inch			
	White	4500 White	Daylight	Soft White
6-W 9″ T-5	5.8	5.5	5.2	*
8-W 12″ T-5	6.5	6.1	5.8	*
13-W 21″ T-5	6.0	5.6	5.3	*
14-W 15″ T-12	3.1	2.9	2.8	2.4
15-W 18″ T-8	4.6	4.5	4.4	3.6
15-W 18″ T-12	3.0	2.9	2.7	2.3
20-W 24″ T-12	3.2	3.0	2.8	2.4
30-W 36″ T-8	5.0	4.7	4.6	4.0
40-W 48″ T-12	3.9	3.6	3.3	2.9
100-W 60″ T-17	4.1	3.9	3.8	3.2
Instant-Start				
40-W 48″ T-12	3.9	3.6	3.3	...
40-W 60″ T-17	...	2.0	...	...
Slimline				
16-W 42″ T-6	3.8	3.5	...	...
25-W 42″ T-6	5.8	5.4	...	...
33-W 42″ T-6	**	6.6	...	...
24-W 64″ T-6	3.8	3.5	...	...
39-W 64″ T-6	5.8	5.4	...	...
51-W 64″ T-6	**	6.6	...	...
22-W 72″ T-8	2.3	2.2	...	...
38-W 72″ T-8	3.9	3.6	...	...
51-W 72″ T-8	**	4.7	...	...
29-W 96″ T-8	2.3	2.2	...	...
51-W 96″ T-8	3.9	3.6	...	...
69-W 96″ T-8	**	4.7	...	...
Circline				
32-W 21″ Diam. T-10	4.5	...	...	...

* Brightness approximately 25% lower than for White lamp.
** Brightness approximately 5% higher than for 4500 White lamp.

source in the same type of equipment. When it is desired to further reduce the source brightness, as is necessary for most applications involving critical seeing, diffusing materials of relatively light density may be satisfactorily employed.

Stroboscopic Effect

Some variation in light output with the cyclic variation of the current is characteristic of all light sources operated on alternating current. The filament of an incandescent lamp retains enough heat so that its drop in light output at the point of zero current flow is not noticeable, except occasionally when low-wattage lamps are operated on a 25-cycle supply. With fluorescent lamps the arc is completely extinguished twice during each cycle, and the carry-over of light is dependent wholly on the phosphorescent qualities of the coating. This characteristic of the phosphors varies considerably. The phosphor used in the Green lamp has the greatest carry-over, while that used in the Blue lamp has the least.



The *stroboscopic effect* (the tendency to see multiple images of an object in motion) which results from rapid fluctuation in light output may be an important consideration where moving objects are to be viewed. The standard two-lamp lead-lag ballast reduces stroboscopic effect to a point where for ordinary applications it is negligible. Where still further reduction is necessary, operation of three adjacent lamps or pairs of lamps on separate phases of a three-phase system will result in a freedom from flicker comparable to that of most filament lamps.

The table shows the relative stroboscopic effect of various light sources expressed as the ratio of the light output above mean average during a cycle to the total output at mean average. The stroboscopic effect of a 200-watt filament lamp is taken as unity.

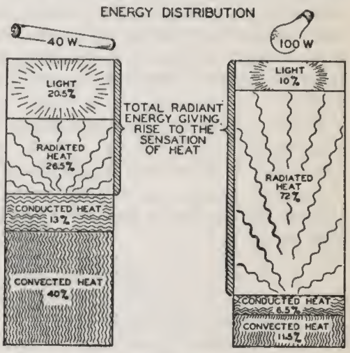
COMPARATIVE STROBOSCOPIC EFFECT OF VARIOUS LAMPS
Operated on 60-Cycle Supply

Lamp and Method of Operation	Relative Stroboscopic Effect
200-Watt Incandescent	1
40-Watt Incandescent	7
Green Fluorescent—Single-Lamp Ballast	11
White Fluorescent—Single-Lamp Ballast	19
Blue Fluorescent—Single-Lamp Ballast	49
White Fluorescent—Two-Lamp Ballast	9
White Fluorescent—Three Lamps, Single-Lamp Ballasts on Separate Phases of a Three-Phase Circuit	3
White Fluorescent—Three Lamps, One on Single-Lamp Ballast, Remaining Pair on Two-Lamp Ballast	14

Coolness

The fluorescent lamp, primarily because of its higher efficiency, produces light with considerably less accompanying heat than the filament lamp. This is because the total heat developed by any light source is in direct proportion to its energy consumption (one watthour of power consumed produces 3.414 BTU's of heat), and because fluorescent lamps at 40 to 60 lumens per watt emit two to three times as much light as filament lamps of the same wattage, while generating the same amount of heat.

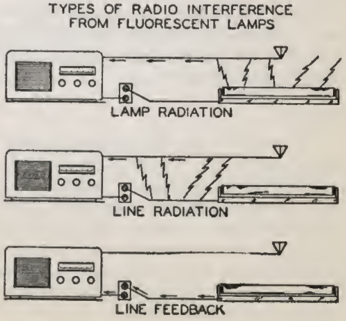
A further difference between the two types of lamps is the form which the heat takes. Not only does the fluorescent lamp produce less total heat for a given amount of light, but less than half of the heat it does produce is in the form of radiant energy (*radiated heat plus light*), whereas about three-quarters of the heat from a filament lamp is radiant energy. Thus for equal light output the radiant or *sensible* heat generated by fluorescent lamps is approximately one-fifth of that produced by filament lamps. Conducted and convected heat, which accounts for the balance of the total energy, is chiefly dissipated upward, and contributes much less to the sensation of heat derived from the lighting installation.



Where total heat is a consideration, as for instance in the computation of air-conditioning load, the quantity that is important is of course total lamp wattage, rather than radiant heat. It is also necessary to add to the lamp wattage the watts consumed by any ballasts located within the area in question.

Radio Interference

The mercury arc of a fluorescent lamp causes a sparking action on the lamp electrodes which sets up a series of low-power radio waves. These waves are picked up by radio receiving sets, and may cause interference in the form of a buzzing sound. The noise is generally heard only between stations on the dial, but it may also be noticeable over the entire broadcast band. Interference from fluorescent lamps can readily be identified by tuning the set to a point where the interference is most pronounced, and then turning off the lamps. If the noise persists, it is of course from some source other than the lamps.



There are three ways in which radiation from fluorescent lamps may reach the radio and interfere with reception:

1. Direct radiation from the lamp to the radio aerial circuit.

2. Line radiation from the electric supply to the aerial circuit.

3. Line feedback from the lamp through the power line to the radio.

Most radio interference from fluorescent lamps is eliminated by the small condenser ordinarily mounted in the starter-switch container. Starterless systems require that the condenser be mounted in the ballast. Manual starting switches should also be provided with suitable condensers such as are regularly supplied in glow-switch starters. These condensers should have the following minimum values:

14, 15, 20, 30, and 40-watt lamps—0.005 microfarads
100-watt lamps—0.010 microfarads.

If further measures prove to be necessary, radio-interference filters which are commercially available will give excellent results when properly installed. The simplest of these is a three-section delta-connected capacitor which is grounded to the fixture and connected across the supply lines as they enter the fixture. In most cases these filters will reduce radio interference caused by fluorescent lamps to a level not detectable by the ear. A filter should be installed on each fixture, and as close to the lamps as possible.

Direct radiation from the lamp diminishes rapidly as the radio aerial is separated from the lamp. If the radio and aerial are at least 9 feet from the lamp, interference by direct radiation is negligible.

In rural areas, and in places where radio station signal strength is weak, it may be necessary to take the following additional precautions for best results:

1. Connect the aerial to the radio by means of a shielded lead-in wire with the shield grounded, or install a "doublet" type aerial with twisted-pair leads.
2. Provide a good radio-frequency ground for the radio.
3. Place the aerial itself out of bulb- and line-radiation range.
4. Use an outside aerial to provide a strong radio signal.

Noise

With any reactor or transformer, some audible frequencies, or "hum," generated by the alternating magnetic force are inevitable. Well-made fluorescent auxiliaries and fixtures are now designed to reduce hum to a point where it is rarely objectionable. The degree of ballast noise acceptable of course varies with the application. Hum is seldom noticeable in factory spaces or other moderately noisy areas, but it may become annoying in particularly quiet rooms, or where the ballast is very close to the user. Under extreme conditions it may be necessary to locate auxiliaries at a remote point, or in soundproof cases. Hum is additive, and a large number of units may require special attention where a single one would cause no difficulty.

Swirl

An occasional fluorescent lamp may exhibit what is called a "swirl," which may be described as a moving spiral band of brightness. Swirl is ordinarily encountered only with new or relatively new lamps, and generally disappears after a short period of burning. Sometimes it may be corrected by turning the lamp off and restarting it after it has cooled slightly. The condition may be aggravated somewhat by inadequate preheat current supplied by the ballast, inadequate preheat time as regulated by the starter, or lack of a starting compensator in the lead circuit. Swirling is also more prevalent in instant-start than in preheat circuits.

CHAPTER FOUR

INTRODUCTION TO LIGHTING DESIGN

The design of any lighting installation involves the consideration of many variables: What is the purpose of the installation—is it light for critical seeing, light for selling, or light for decoration? How severe is the seeing task, and for what length of time is it to be performed? What are the architectural and decorative requirements, together with the constructional limitations, of the area? What economic considerations are involved? The answers to questions such as these determine the amount of light that should be provided, and the best means of providing it. Since individual tastes and opinions vary, especially in matters of appearance, no one solution of a lighting problem will be the most desirable under all circumstances. However, there are certain basic rules governing adequate quantity and good quality which should always be observed.

QUANTITY OF LIGHT

One of the most obvious measures of the adequacy of a lighting installation is the amount of illumination it provides. The tables in Chapter Five list many of the more common seeing tasks, together with the footcandle levels which are considered good present-day practice.

Compared with the levels ordinarily encountered in nature, the values listed in Chapter Five are low. They are low not because low levels are satisfactory for critical seeing, but rather because of present limitations in our ability to produce higher levels comfortably and economically. The comfort and ease of performing most close visual tasks can be materially improved by illumination intensities far above those now practically attainable.

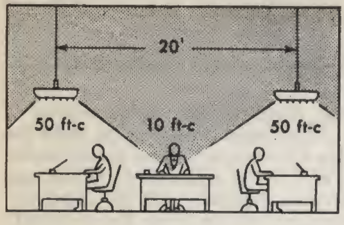
REPRESENTATIVE LEVELS OF ILLUMINATION

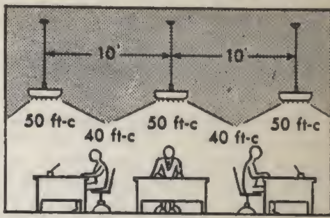
	Footcandles
Starlight	0.0002
Moonlight	0.02
Street Lighting	0.6–1.2
Daylight	
At North Window	50–200
In Shade (Outdoors)	100–1000
Direct Sunlight	5000–10000
Office Lighting	30–50

Thus footcandle recommendations may reasonably be expected to increase with the improvement of sources and the ability to use them, and the tables in Chapter Five obviously do not represent the ultimate in seeing-comfort. They do, however, serve as a guide to the values which are practical in the present state of the illumination art. By listing the footcandles necessary to provide equal seeing-ease, they also give a rough indication of the relative severity of various seeing tasks.

The distribution of illumination, as well as its average footcandle level, should be determined by the purpose of the installation. In light for seeing or light for production it is usually desirable to position the luminaires so as to provide reasonably uniform general illumination over the entire area. The ratio of maximum footcandles under the luminaires to the minimum between them should never be greater than two to one, and for best results should be nearer unity. Units with wide distribution

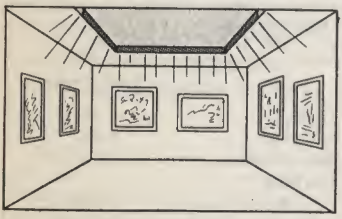
characteristics can be spaced farther apart, for the same mounting-height, than those with more concentrated distribution. Maximum spacing-to-





mounting-height or ceiling-height ratios for various types of equipment are supplied by the manufacturers. It should be noted that these figures are maximum values from the standpoint of reasonable uniformity alone, and that closer spacings are often necessary to produce the desired illumination levels.

Where it is advantageous to concentrate light on specific work areas, or where light is used for dramatic or decorative effect, uniform illumination may not be desirable. In most restaurants and night clubs, for example, contrast produced by variation in illumination helps to create an attractive atmosphere. In certain types of merchandising it is good practice to direct more light to display and sales areas than to general traffic areas, and in many other circumstances the most effective use of light involves marked departure from a uniform distribution.



The specific plane on which the illumination is to be provided must also be considered. The seeing task may be located on a horizontal plane at a desk or a machine, on a vertical or sloping surface, or even on the under surface of large objects such as airplane assemblies. It is always desirable to select luminaires which will best light the specific work area.

QUALITY OF LIGHT

Adequate *quantity* of light alone does not ensure good illumination. Good *quality* is as important as quantity, and usually more difficult to achieve. The factors involved in lighting quality are many and complex, but *glare, brightness ratios, diffusion,* and *color* may be listed as among the most important.

Glare

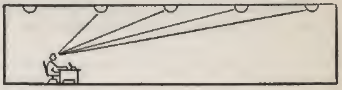
Glare is any brightness that causes discomfort, interference with vision, or eye fatigue. While it is difficult to evaluate the various elements of glare mathematically, certain specific determining factors have been established:

1. The brightness of the source. The higher the source brightness, the greater the discomfort and the interference with vision.

2. The size of the source, expressed in terms of the angle subtended at the eye. A large area of low brightness such as a luminous panel, or a

number of low-brightness luminaires, may be as uncomfortable as a single small source of higher brightness.

3. **The position of the source.** Glare decreases rapidly as the source is moved away from the line of vision. A luminaire suspended in the range of vision is more glaring than the same luminaire mounted above the normal viewing angle.



4. **Brightness contrast.** The greater the brightness contrast between a source of glare and its surroundings, the greater the glare effect.

5. **Time.** A condition which is not objectionable for an exposure of a few minutes may become intensely uncomfortable and fatiguing to a person who must work under it for an eight-hour day.

Thus a consideration of the possible glare effect of a lighting installation involves not only the intrinsic brightness of the individual fixture or element, but also many characteristics of the room and the conditions of use. Luminaire brightnesses which are quite comfortable in a small office where the units are out of the range of vision may be excessive in larger rooms where the luminaires farthest away more nearly approach the normal line of sight. Likewise, luminaires which individually do not have an objectionably high brightness may, if mounted in large groups, present a total area great enough to cause discomfort. This occasionally results when some types of fluorescent luminaires are mounted across the line of sight in large areas with relatively low ceilings.

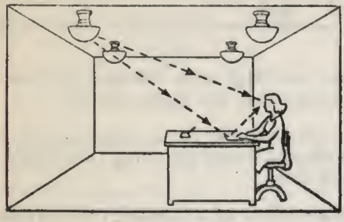
Obvious precautions against excessive glare are the shielding of all lamps within the field of view, the use of light colors on ceilings and walls to reduce contrast, the mounting of light sources above the normal line of vision wherever possible, and the restriction of fixture brightness to reasonable limits. Where illumination for critical seeing is to be provided, the maximum brightness of conventional luminaires within an angle of 30° to 45° above the line of sight should be about 400 footlamberts (0.9 candles per square inch). For larger sources, such as indirectly lighted or completely luminous ceilings, approximately 170 footlamberts (0.4 candles per square inch) may be regarded as the upper limit. These values have been found to be satisfactory for a general illumination level of about 50

APPROXIMATE BRIGHTNESS VALUES

Source	Candles per Square Inch	Foot-lamberts
Inside Frosted Lamp (300-Watt)	30	13,560
Clear Lamp (300-Watt)	6000	2,712,000
White Bowl Lamp	15	6,780
Fluorescent Lamps	2.0 to 6.5	904 to 2938
Opal Glass Enclosing Globes	1.5 to 5.5	678 to 2486
Indirect Luminaire (Incandescent Luminous Bowl)	0.5 to 1.0	226 to 452
White Ceiling Above Direct-Indirect Fluorescent Luminaire	0.5	226
Clear Blue Sky	2 to 3	904 to 1356

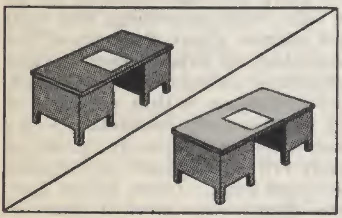
footcandles, with walls, ceilings and floors of commonly prevailing reflecting characteristics. Lower footcandle levels require lower luminaire brightnesses, whereas somewhat higher brightnesses may be allowable with intensities above 50 footcandles.

The preceding paragraphs deal primarily with *direct glare*, caused by light coming directly to the eye from a source, or a bright surface in the field of view. The image of a light source (or any object of high brightness) reflected from a specular surface in the direction of the eye can cause *reflected glare*, which may be as uncomfortable and annoying as direct glare. Shiny surfaces such as machined metal, polished desk tops, cellophane index tabs, or even glossy paper, are often sources of reflected glare. Since specular reflection is directional, it is frequently possible to prevent reflected glare by positioning the light source, the work surface, or the worker so that the reflected light will be directed away from the eyes. Reflected glare may also be controlled by means of large-area low-brightness sources, and by using light colors, with dull, non-glossy reflecting finishes, on furniture and working surfaces.



Brightness Ratios

Excessive *brightness ratios* in the field of view, or *brightness contrasts* between adjacent surfaces, even though not severe enough to be called "glare," may be seriously detrimental to lighting quality. For example, a high brightness of the task with a comparatively low brightness of the surroundings is definitely undesirable, since it forces continual adjustments of the eyes from one brightness level to the other. Brightnesses in the peripheral field higher than the brightness of the task tend to attract the eye away from the task, and are therefore also to be avoided.



Extensive studies of the seeing process have shown that the ideal situation for critical seeing is a background brightness equal to the brightness of the task. This condition is, of course, seldom achieved, and a task-to-immediate-surroundings brightness contrast no greater than three to one is usually acceptable. Ratios no greater than ten to one anywhere in the visual field are desirable, 30 or 40 to one being commonly considered as the maximum permissible. These values, like allowable absolute brightnesses, vary somewhat with illumination level, the maximum permissible ratio becoming smaller as the contrast sensitivity of the eye increases with higher footcandle values.

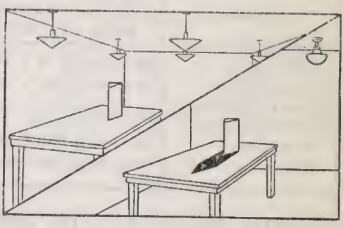
The achievement of comfortable brightness ratios in any given situation requires a careful study of all the factors involved, including not only the light sources and luminaires but also the reflecting characteristics of ceilings, walls, floors, and furnishings, and the illumination on them. For

best results it is necessary to create a proper balance between the brightness of the immediate working area and that of other surfaces in the visual field, avoiding both excessively dark backgrounds and distracting surrounding areas of high brightness. Although special conditions require many exceptions to the general rule, the reflection factors for room surfaces listed in the accompanying table are those which have been found to be commonly satisfactory under typical conditions, with average present-day footcandle levels.

REPRESENTATIVE DESIRABLE REFLECTION FACTORS	
Ceilings	75–85%
Walls	50–60%
Desk Tops	25–35%
Floors	15–30%

Diffusion

Illumination which results from light coming from many directions, as opposed to light from one direction, is said to be *diffuse.* Diffusion is a function of the number or physical size of the light sources contributing to the illumination at a particular point, and is measured in terms of the absence of sharp shadows.



The degree of diffusion desirable depends on the type of work to be performed. Perfectly diffuse light is the ideal illumination for many critical seeing tasks, and in such applications as school and office lighting an effort is usually made to achieve as high a degree of diffusion as is consistent with economic and other limitations. Where polished metal surfaces must be viewed, as in a machine shop, a highly diffuse light is essential to prevent annoying specular reflections.

In many applications, on the other hand, it is desirable to provide directional illumination. For example, surface irregularities which are almost invisible under diffuse light may be clearly revealed in light directed at a grazing angle. Some details are most readily seen by means of glint, or specular reflection from small areas, which would be absent under completely diffuse illumination. Directional light is desirable in producing modeling effects on merchandise displays, and aesthetic considerations frequently dictate the addition of some directional component in general lighting installations, to prevent the uninteresting and monotonous appearance resulting from completely diffuse lighting.

Diffusion is achieved by means of a multiplicity of light sources, by large-area low-brightness luminaires, by indirect or partially indirect lighting in which the ceiling and walls become secondary sources, and by light-colored matte finishes on ceilings, walls, furniture, and even floors. A reasonable degree of diffusion results from the use of wide spread direct lighting equipment in high-ceilinged areas, since a large number of units are effective at any given point. Fluorescent direct luminaires ordinarily provide more diffuse illumination than incandescent direct luminaires, and large-area hoods or diffusing panels provide still greater diffusion.

Color

The color of light has no effect on visual efficiency. For the performance of ordinary visual tasks, no light source has an advantage over any other from the standpoint of color. However, in some specialized applications —notably color matching, color discrimination processes, and certain inspection tasks—light-source color may be an important factor in illumination quality. Moreover, other considerations, quite apart from the ability to see easily, often influence the choice of the most suitable light-source color for a given purpose. This subject is discussed more fully in the section on Color beginning on page 4-14.

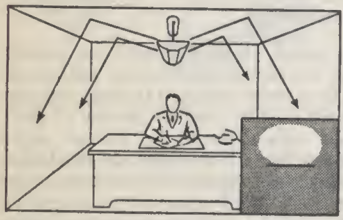
TYPES OF LIGHTING SYSTEMS

Illumination of good quality and adequate quantity may be obtained from any one of several types of lighting systems, classified on the basis of vertical light distribution. The selection of the best type of luminaire for any particular application depends in part on the physical characteristics of the room, the type of work to be performed, and the conditions of maintenance to be encountered.

TYPES OF LIGHTING SYSTEMS

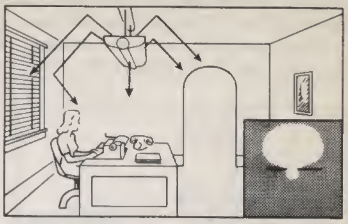
System	Upward Component	Downward Component
Indirect	90 -100%	0 - 10%
Semi-Indirect	60 - 90%	10 - 40%
General Diffuse / Direct-Indirect	40 - 60%	40 - 60%
Semi-Direct	10 - 40%	60 - 90%
Direct	0 - 10%	90 -100%

Indirect—Ninety to 100 per cent of the light output of the luminaire is directed toward the ceiling at angles above the horizontal. Practically all of the light effective at the working plane is redirected downward by the ceiling and to a lesser extent by the side walls. Since the ceiling is in effect the light source, the illumination produced is quite diffuse in character. While indirect lighting is not as efficient as some of the other systems on a purely quantitative basis, the even distribution and absence of shadows and reflected glare frequently make it the most desirable type of installation for offices, schools, and other similar applications. Because room finishes play such an important part in redirecting the light, it is particularly important that they be as light in color as possible, and carefully maintained in good condition. The ceilings should always have a matte finish, if reflected images of the light source are to be avoided.

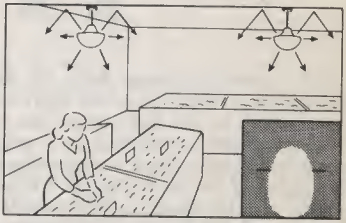


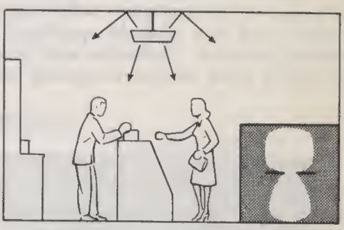
Glass or plastic luminaires in this classification are known as "luminous indirect," while metal luminaires which transmit no light are totally indirect. The translucent type is sometimes more desirable than the totally indirect because a luminous fixture is less sharply silhouetted against the relatively bright ceiling. Indirect illumination may also be provided by means of architectural coves. Luminaire suspension length, or cove proportions, must be carefully selected to provide uniform ceiling coverage, where desired, and to prevent excessive ceiling brightness.

Semi-Indirect—Sixty to 90 per cent of the light output of the luminaire is directed toward the ceiling at angles above the horizontal, while the balance is directed downward. Semi-indirect lighting has most of the advantages of the indirect system, but is slightly more efficient, and is sometimes preferred to achieve a desirable brightness ratio between the ceiling and luminaire in high-level installations. The diffusing medium employed in these luminaires is glass or plastic of a lower density than that employed in indirect equipment.

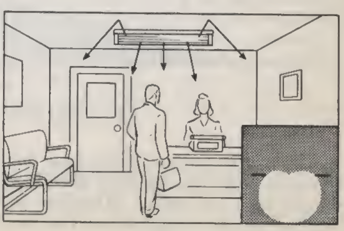


General Diffuse or Direct-Indirect—Forty to 60 per cent of the light is directed downward at angles below the horizontal. The major portion of the illumination produced on ordinary working planes is a result of the light coming directly from the luminaire. There is, however, a substantial portion of the light directed to the ceiling and side walls. Where these are light in color, the upward light provides a brighter background against which to view the luminaire, in addition to supplying a substantial indirect component which adds materially to the diffuse character of the illumination. The difference between the ***general diffuse*** and ***direct-indirect*** classifications is in the amount of light produced in a horizontal direction. The general diffuse type is exemplified by the enclosing globe which distributes light nearly uniformly in all directions, while the direct-indirect luminaire produces very little light in a horizontal direction, due to the density of its side panels. Glass, plastic or louvered bottoms are commonly used with the latter type of luminaire to provide lamp shielding.

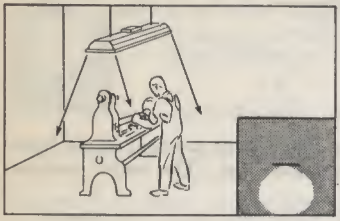




Semi-Direct—Sixty to 90 per cent of the light is directed downward at angles below the horizontal. The footcandles effective under this system at normal working planes are primarily a result of the light coming directly from the luminaire. The portion of the light directed to the ceiling results in a relatively small indirect component, the greatest value of which is that it brightens the ceiling area around the luminaire, with a resultant lowering of brightness contrasts. Equipment of this type is exemplified by the cylindrical glass-enclosed fluorescent luminaire or the open-bottom glass shade for incandescent lamps.

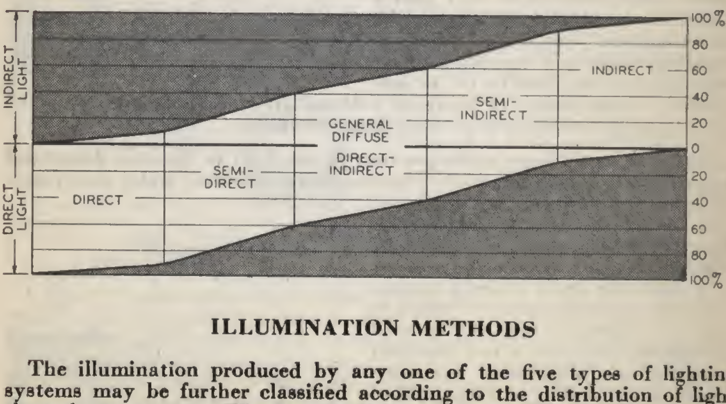


Direct—Ninety to 100 per cent of the light is directed downward at angles below the horizontal. A direct system produces light efficiently from a quantitative standpoint, since there is no ceiling and very little wall absorption. Luminaires of this type may be further classified as *concentrating*, *medium*, or *wide spread*. The wide or medium spread equipment can be used in relatively wide rooms, with the advantage that more luminaires contribute to the illumination at any one point, and better diffusion is achieved. Concentrating equipment is desirable where the luminaires are mounted at a considerable height above the working plane, or where it is necessary to provide illumination within a relatively narrow area. Equipment of this type should be used for high bay installations and for lighting the perimeters of large areas, since little light is lost against walls and windows.



The most common form of direct-lighting equipment consists of a reflecting surface above the light source, which redirects downward a large percentage of the light from the bare lamp. In certain luminaires additional control is obtained by a translucent diffusing or control element of glass or plastic added to the reflector. RLM and high bay luminaires are examples of the first type, and Glassteel diffusers, prismatic control equipment, and luminous ceiling panels of the second. There are other variations in direct-lighting equipment, such as silvered bowl diffusers, which depend on the luminaire reflecting surface to redirect all of the light downward, and the pinhole spotlight, which embodies a reflector and lens control system. Reflector and projector lamps may, under certain conditions, be used as direct-lighting luminaires.

LIGHTING SYSTEMS

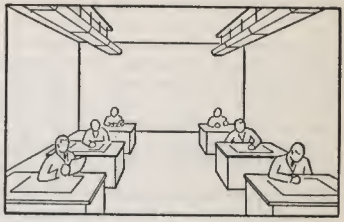


ILLUMINATION METHODS

The illumination produced by any one of the five types of lighting systems may be further classified according to the distribution of light throughout an area. Whether the lighting is *general*, *localized general*, or *supplementary* depends on the location of the equipment, and its distribution characteristics.

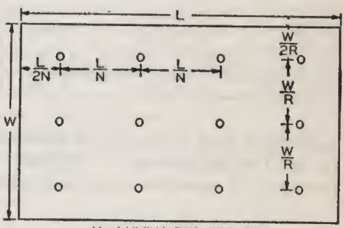
General Lighting

An arrangement of lighting equipment which will produce a reasonably uniform level of illumination throughout an interior is known as general lighting. The physical dimensions of the room, the distribution characteristics of the luminaire, the level of illumination desired, and the appearance of the finished installation are factors which determine equipment location.



Even distribution is most readily obtained by a symmetrical positioning of luminaires. After computing the number of luminaires necessary to produce the quantity of light desired (see Chapter Six), a rough approximation of location should be made so that the total number of luminaires can be adjusted to be evenly divisible by the number of rows. The exact distance between fixtures is determined by dividing the length of the room by the number of luminaires in a row, allowing for one-half of the distance between the wall and the first unit. In a similar manner, the distance between rows is the width of the room divided by the number of rows, with one-half of the distance left between the side wall and the first row.

LOCATION OF LUMINAIRES



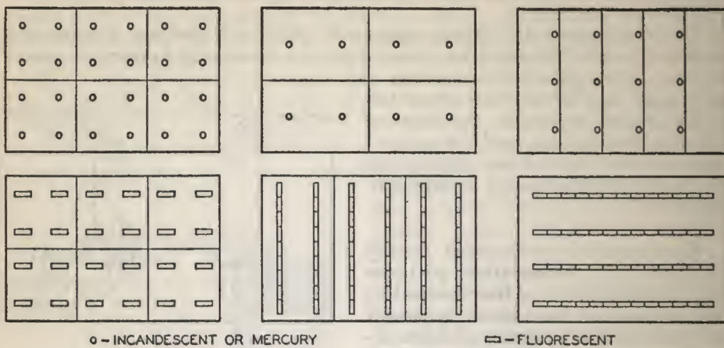
N = LUMINAIRES PER ROW
R = NUMBER OF ROWS

For even distribution of illumination with most types of luminaires, these two dimensions should be approximately equal. In some cases, as when fluorescent luminaires are used to obtain relatively high levels of illumination, appearance and ease of wiring dictate the use of continuous rows of luminaires spaced closed enough together to meet the requirements of good distribution.

The spacing-to-mounting-height ratio must be within the limits established by the distribution characteristics of the luminaire. Particularly in the use of high-wattage sources, care must be exercised in the selection of luminaire capacity, since spacing-to-mounting-height ratios frequently dictate the use of smaller luminaires than would at first seem acceptable. The wider the distribution of the luminaire, the greater the permissible spacing. For this reason indirect luminaires, which make use of the ceiling as a source, can normally be mounted farther apart than direct units.

The constructional features of an area frequently influence luminaire location. Where the ceiling area is divided into bays by beams or trusses, it is usually desirable to install luminaires symmetrically in each bay or pair of bays.

TYPICAL LUMINAIRE LAYOUTS FOR GENERAL LIGHTING

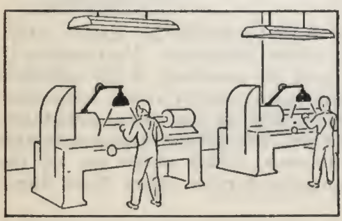


Localized General Lighting

Localized general lighting is the positioning of general-lighting equipment with reference to particular work areas where high intensities are necessary, with the spill light from the same luminaires usually providing sufficient illumination for the adjacent areas. Luminaires of the direct, semi-direct, or direct-indirect type are usually employed for this purpose, since a substantial direct component is essential where it is desired to concentrate most of the light on a restricted area beneath the luminaire. This method of fixture location can be used to advantage for lighting the work points of large machines, sales counters in merchandising operations, and bench locations in factories.

Supplementary Lighting

Supplementary lighting is the provision of a relatively high intensity at specific work points by means of direct-lighting equipment used in conjunction with general or localized general illumination. It is frequently necessary where especially critical seeing tasks are involved, and where it is not feasible to provide the desired intensity by either of the other methods; also where light of a directional quality is required for certain inspection operations. Equipment used for this purpose varies in distribution characteristics depending on the area to be covered, the distance from the equipment location to the work point, and the footcandles required. Care must always be exercised to keep a reasonable relationship between the intensities of the general illumination and the supplementary lighting, since an excessive brightness ratio between the work point and its surroundings creates an uncomfortable seeing condition.



CHOICE OF LIGHT SOURCE

The choice of light source—filament, mercury vapor, or fluorescent—depends largely on appearance and economics. In certain applications the large area of the fluorescent lamp is advantageous from the standpoint of low brightness and minimum reflected glare. On the other hand, where accurate control is desired the smaller sources with their higher brightnesses are more effective.

The operating characteristics of fluorescent or mercury vapor lamps must be carefully considered if it is proposed to install them in locations where they will be turned on and off at frequent intervals, or where they will be subjected to excessive fluctuations in supply voltage, or to temperature extremes. In cases where existing wiring capacity limits wattage load, a fluorescent installation is often the only possible solution to the problem of providing higher illumination levels. Under some circumstances light-source color and the creation of a pleasing effect may be a determining factor in favor of one or another type of lamp.

Air-conditioning load may be another consideration, expecially at high illumination levels. Filament lamps produce approximately five times as much total radiant energy, for a given amount of light, as fluorescent lamps. This radiation is absorbed, by walls, ceilings, furnishings, and room occupants, in the form of heat, which may or may not be an advantage, depending on room temperatures and other conditions. Usually it is desirable from the standpoint of comfort to keep the heat produced by the lighting system to a minimum. Where air conditioning is involved, the use of the higher-efficiency sources reduces the capacity of the equipment required, and results in lower first cost and operating cost. The air-conditioning load resulting from the lighting system must be calculated on the basis of the total wattage of the system. For incandescent installations this is simply the sum of the wattages of all the lamps, but for fluorescent or mercury installations the wattage of the ballasts or transformers must be added to that of the lamps. The wattage load of an incandescent installation is about two and one-half times that of a fluorescent installation providing equal footcandles.

CALCULATION OF AIR CONDITIONING REQUIRED FOR LIGHTING LOAD

1 Watt = 3.414 BTU
1 Kilowatt = 3414 BTU

BTU generated per hour = Lighting kilowatts* x 3414

Tons of air conditioning required = $\dfrac{\text{BTU per hour}}{12000}$

* Total lamp wattage plus wattage of auxiliary equipment.

Aside from these special considerations, the choice of a light source is largely a matter of a cost analysis involving original cost of equipment and wiring; operating cost including power, maintenance, and lamp replacements; and other related items such as the cost of air conditioning. A form for such an analysis is given in Chapter Fifteen.

CHOICE OF EQUIPMENT

Proper candlepower distribution for the particular lighting application should be the first consideration in the selection of lighting equipment. Luminaires should be chosen for distribution characteristics suitable to the requirements of the given situation.

The efficiency of a luminaire is one measure of the quality of its material and design. Any control applied to the light output of a bare lamp results in some absorption of light. Ordinarily the greater the degree of control attained, the greater the light loss. In many installations the use of low-efficiency equipment is justifiable in order to achieve a desired effect. Therefore it is impractical to compare the efficiencies of dissimilar types of equipment. However, luminaires which produce the same type of control can be compared on an efficiency basis, and those with higher efficiencies are to be preferred.

Electrical features of luminaires warrant careful consideration in the interest of trouble-free, efficient operation. Equipment built to conform to underwriters' specifications and certified by laboratory tests can usually be relied on to provide the most satisfactory results.

Mechanical construction is important in all types of luminaires, but requires special attention in those designed for the longer fluorescent light sources. It is important that the metal parts be sufficiently strong to maintain the various elements in proper alignment, and to support the comparatively heavy equipment with safety. The accessibility of lamps and other electrical parts for service and for cleaning is also an important consideration.

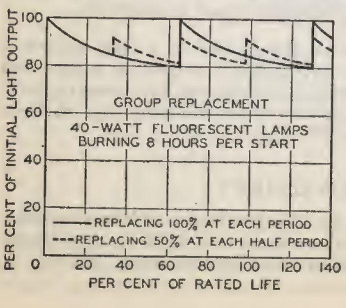
The appearance of the luminaire should be studied with respect to the architecture and decoration of the area in which it is to be used. The requirements will depend to some extent on whether the lighting equipment is functional, decorative, or both. In any event, it should harmonize with the surroundings in architectural style, size, and decorative motif.

OTHER CONSIDERATIONS IN DESIGNING A LIGHTING INSTALLATION

Maintenance

The illumination produced by any lighting installation depreciates with the gradual reduction in light output of the lamps due to age and use, and the lowered efficiency of luminaires and room surfaces caused by an accumulation of dirt. In the design of any lighting system it is essential not only to properly evaluate the effect of each of these factors, but also, so far as possible, to select and locate equipment for easy maintenance.

Light sources vary both in length of life, and in light output during life. The problem of depreciation in light output becomes more pronounced with long-life sources such as fluorescent and mercury vapor lamps, since the light produced near the end of life may be less than 75% of the original value. It is frequently found to be economical to establish a replacement program in which new lamps are installed before the old ones have reached the end of life. Such a program can best be carried out by systematically replacing the lamps in a specific area after they have burned a predetermined number of hours. This procedure is



commonly termed "group replacement," and the period selected for lamp renewal should be somewhat less than the rated life. All of the lamps in the area may be replaced at one time, or distributed portions of them may be replaced at separate intervals. The latter method has an advantage in that it results in less variation in the illumination level effective in the area. Still less variation results where lamps are replaced on burn-out only, once the replacement rate has become constant. The best replacement method for any particular installation is determined by accessibility of equipment and cost of individual replacements.

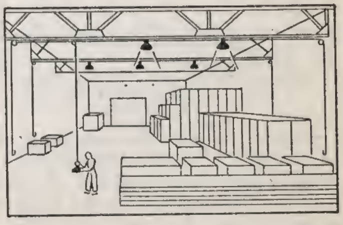
Luminaires do not function efficiently when covered with dirt. Not only is light lost by being forced to travel through a layer of dust, but with many types of luminaires the installation is rendered less effective by a change in the distribution characteristics of the equipment. This is especially true where specular reflecting surfaces are employed to produce concentrated beams of light, since an accumulation of dirt on a specular surface causes it to become diffuse in character.

Where parts may be hard to handle because of weight, size, or inaccessibility, they should be hinged or otherwise secured to the main body of the luminaire. For purposes of cleaning it is an advantage to be able to remove the lamps and reflecting equipment readily.

For normal ceiling heights regular stepladders can ordinarily be used for access to the fixtures. Where ceilings are high or where the floor area beneath the luminaires is inaccessible, telescoping ladders with extension platforms may be required. These are frequently necessary for use in machine shops and large auditoriums.

The most desirable method of servicing equipment mounted high above the floor is from above the ceiling or from a catwalk. Space is frequently available above suspended ceilings from which recessed equipment can be relamped and cleaned. In many high bay industrial areas the lighting equipment is serviced from catwalks supported by the building trusses. Luminaires located near the catwalk can be equipped with swing-out type mountings. Luminaires at a greater distance can be supported from a messenger cable and pulley arrangement permitting them to be pulled over to the catwalk for servicing. Where high bay areas are equipped with a crane, the lighting equipment can be mounted so that it is accessible from a platform on the bridge of the crane.

Another method of obtaining access to lighting equipment is a disconnecting or lowering-type hanger which permits the luminaire to be brought down to the point of servicing by means of a cable. The cable can be operated from any easily accessible location.



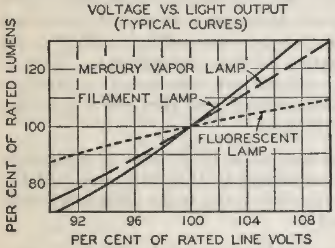
Where floodlighting equipment can be mounted on building parapet walls, swing-over type mountings make it possible to provide maintenance from the roof. Hinged poles are available which give access to floodlights without the use of ladders.

Room surfaces contribute to the efficiency of an installation in varying degrees depending on the type of lighting system. A reduction in the reflection factor due to dirt has less effect in a direct system than in an indirect, or partly indirect, one. The necessity for cleaning or refinishing

room surfaces varies with conditions. In areas where the dirt sticks to surfaces, walls and ceilings should be reconditioned once or twice a year. Where the dirt condition is less severe, or where air-cleaning systems are employed, room surfaces may be permitted to go several years between servicings.

Voltage

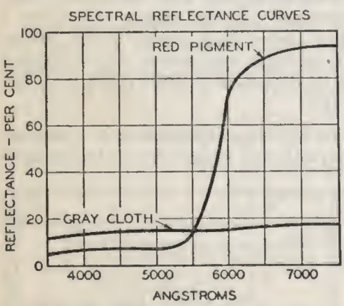
Proper voltage is necessary for the efficient operation of all types of lamps, and the provision of a voltage within the limits prescribed for the equipment is one important factor in lighting design. When adding load to old installations, it is especially important to check the capacity of the system to be certain that adequate voltage will be maintained.



The characteristic curves of incandescent, fluorescent and mercury vapor lamps indicate the variation in light output caused by variation in voltage. Where voltages fall below certain limits, fluorescent and mercury lamps may fail to start, or if operating, may be extinguished.

Color

Recognition of the importance of light-source color in the success of a lighting installation involves an understanding of the basic process by which color is produced. The color of a light source depends upon the wavelengths of light which it generates. The apparent color of a reflecting surface is determined by two things: the spectral reflectance characteristics of the surface (reflection factor for each wavelength throughout the visible spectrum), and the spectral composition of the light by which it is illuminated. A colored object is colored because it reflects light selectively.

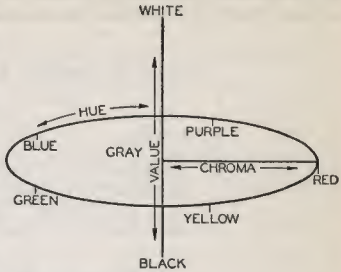


The spectral reflectance curve of a red paint, for example, shows that it reflects a high percentage of the red wavelengths, and little or none of the blue-green end of the spectrum. Red paint illuminated by white light appears red because it reflects the red wavelengths which are part of the white light, and absorbs most of the others. If, however, it is illuminated by light which contains little or no red, such as that from mercury vapor lamps, it reflects very little light, and appears nearly black.

In other words, the only fixed color attribute of any object is its ability to modify the spectral quality of the light incident upon it. A white or a neutral gray body reflects all wavelengths equally. Hence the spectral quality of the light reflected from it is the same as that of the light incident upon it, and it has no "color."

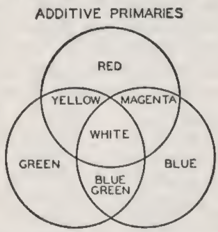
Color is usually specified in terms of three characteristics, *hue*, *value*, and *chroma*. One common method of representing this relationship is by means of a three-dimensional color solid, in which hue (red, green, blue, etc.) is indicated by position around the exterior; value by vertical posi-

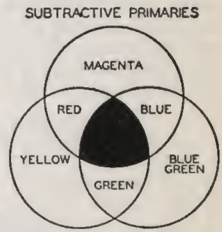
tion, the lightest colors being at the top and the darkest at the bottom; and chroma by horizontal position between the central, or neutral gray, axis and the pure spectrum colors around the circumference. Thus the hue of a color specifies its *dominant spectral region* or *wavelength,* its value indicates its *brightness,* and its chroma is a measure of its *purity,* or how great a proportion of other wavelengths are mixed with the dominant wavelength. The value of a pigment is closely related to its reflection factor for white light; the higher the value, the higher the reflection factor. The three analogous terms by which the color of *light* is sometimes described are *hue, brightness,* and *saturation.*



Colors may be mixed by *additive* or *subtractive* means. The mixing of colors of light by projecting them on the same surface is an additive process. The creation of color by filtering white light, or by the mixing of pigment colors, is a subtractive process. Red, blue, and green, the additive *primary colors,* when mixed in the proper proportions produce white light. The three subtractive primaries are yellow, blue green, and magenta. Combined subtraction of all three makes black, whereas combined subtraction of pairs yields the additive primaries. Two colors that combine to give white or a neutral gray are said to be *complementary* colors. The subtractive primaries are complements of the additive primaries. When black is mixed with a color, the result is popularly known as a *shade* of the original color; mixing white with a color produces a *tint.*

TERMINOLOGY	
Pigment	**Light**
Hue Value Chroma	Hue Brightness Saturation





Strongly colored light is, of course, not ordinarily used for seeing purposes but for its decorative, dramatic, and attention-compelling qualities. Colored light is produced from filament lamps by the subtractive process, whereas fluorescent lamps produce color directly. As a result, colored light is obtainable from fluorescent lamps at much higher lumens per watt efficiencies than from filament lamps. Where concentrated beams of light are desired for display purposes, color caps are used in conjunction with incan-

EFFICIENCY OF PRODUCTION OF COLORED LIGHT

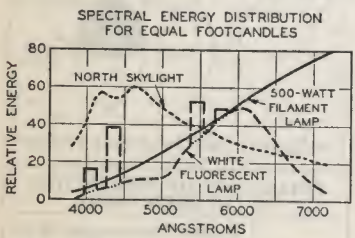
Color	Approx. Lumens per Watt	
	Fluorescent	*Filament
Blue	20 — 26	0.5 — 1.5
Green	55 — 75	0.5 — 3
Yellow	22 — 31	5 — 10
Red	3 — 5	1 — 4

* Based on 100-watt lamp with typical color filters of various kinds: colored bulbs, glass roundels and caps, gelatins, dyes and lacquers.

descent spot or floodlighting equipment, or with projector or reflector lamps. As an indication of the results to be expected, the accompanying table lists the appearance of several colors of paint when light from a strong colored spotlight is added to common types of general illumination.

EFFECT OF COLORED LIGHT ON COLORED OBJECTS				
Object Color	**Red Light**	**Blue Light**	**Green Light**	**Yellow Light**
White	Light Pink	Very Light Blue	Very Light Green	Very Light Yellow
Black	Reddish Black	Blue Black	Greenish Black	Orange Black
Red	Brilliant Red	Dark Bluish Red	Yellowish Red	Bright Red
Light Blue	Reddish Blue	Bright Blue	Greenish Blue	Light Reddish Blue
Dark Blue	Dark Reddish Purple	Brilliant Blue	Dark Greenish Blue	Light Reddish Purple
Green	Olive Green	Green Blue	Brilliant Green	Yellow Green
Yellow	Red Orange	Light Reddish Brown	Light Greenish Yellow	Brilliant Light Orange
Brown	Brown Red	Bluish Brown	Dark Olive Brown	Brownish Orange

Since most of the light sources used for general illumination have continuous spectra, and since most paints and dyes have wide reflectance curves, reflecting some light throughout the greater part of the spectrum, any variation in the relative amounts of each of the colors in so-called "white" light may appreciably alter the appearance of colored objects. The color quality of a "white" light source is sometimes described in terms of *color temperature* (see Chapter Two). The assignment of a color temperature to a light source means that the light produced is similar in color to the light emitted by a blackbody at that temperature. Tungsten has a spectral energy distribution very closeto that of a blackbody, and therefore the visible radiation from a filament lamp is nearly identical, not only in color, but also in relative spectral energy distribution, to blackbody radiation. With fluorescent lamps the situation is somewhat different. While the White (3500°K), 4500 White, and Daylight (6500°K) fluorescent lamps are sufficiently close to a blackbody in *color* so that color temperatures can be assigned to them, in *spectral energy distribution* they differ in varying degrees from the corresponding blackbody curves. These variations are the cause of the accentuation of certain colors by fluorescent light as compared with the same colors under natural light.



The spectral quality of a light source used for color matching or color discrimination requires special consideration. It is also important that the quantity of illumination be constant. Artificial light has a distinct advantage over daylight in constancy of both quality and quantity, and its color can be adjusted to be satisfactory for most of these special applications.

To match exactly under all kinds of light two samples must, of course, have identical spectral reflectance curves, and it is sometimes advisable to check a match under several sources of widely differing spectral quality. For most color matching, however, an attempt is made to reproduce some phase of daylight. Where the requirements are not too critical, the Daylight fluorescent lamp may supply a sufficiently close approximation to average daylight. Filament lamps with carefully selected blue filters are often used where greater accuracy is demanded.

The best light source for detecting small color differences is often one that is relatively poor in energy in the spectral region where the test object has its maximum reflectivity, or, in other words, a light source complementary in color to the sample. Both color matching and color discrimination require relatively high levels of illumination.

The most common type of problem involving light-source color concerns the effect of general illuminants on the colors of wall paints, decorative fabrics, and furnishings. The colors of objects as they appear under average daylight are commonly accepted as their "natural" colors. Since no artificial light source exactly duplicates daylight in spectral distribution, these "natural" colors will be modified to some extent by any lighting system, and the change may be great enough to throw out of balance a carefully planned color harmony.

EFFECT OF VARIOUS ILLUMINANTS ON INTERIOR PAINT COLORS

Paint Color	Munsell Color Designation	* Approx. Reflect. Factor	Filament	Soft White Fluorescent	White Fluorescent	4500 White Fluorescent	Daylight Fluorescent
Cherry Red	5.0 R 4/14	.13	Brilliant Orange Red	Pinkish Red	Pale Orange Red	Yellowish Red	Light Red
Orchid	10.0 RP 7/8	.44	Light Pink	Dusky Pink	Gray Pink	Light Pink	Good Match (grayer)
Plum	10.0 RP 2/2	.04	Deep Orange Red	Reddish Purple	Dark Brown	Light Reddish Brown	Deep Bluish Purple
Chestnut Brown	7.5 YR 5/2	.19	Medium Yellow Brown	Pinkish Brown	Gray Brown	Light Brownish Gray	Light Gray
Peach	2.5 YR 8/4	.58	Pinkish Yellow	Light Pink	Light Yellowish Pink	Very Light Pink	Fair Match (lighter)
Orange	5.0 YR 7/8	.44	Bright Orange	Light Pink	Pale Yellow	Light Yellow	Gray Yellow
Canary Yellow	10.0 YR 7/8	.44	Orange Yellow	Light Orange Yellow	Greenish Yellow	Light Yellow	Fair Match
Light Yellow	2.5 Y 8/8	.58	Vivid Orange Yellow	Pinkish Yellow	Medium Yellow	Light Bright Yellow	Light Greenish Yellow
Sea Foam Green	7.5 GY 8/4	.58	Greenish Yellow	Very Light Gray	Weak Gray Green	Light Yellowish Green	Good Match
Jade Green	2.5 G 5/4	.21	Vivid Yellow Green	Pale Gray Green	Weak Yellowish Green	Yellow Green	Fair Match (lighter)
Light Blue	5.0 BG 7/4	.46	Light Yellowish Green	Light Bluish Gray	Weak Greenish Blue	Blue Gray	Fair Match (lighter)
Medium Blue	5.0 PB 5/10	.23	Blue Green	Weak Gray Blue	Purplish Blue	Light Gray Blue	Fair Match (lighter)
Silver Gray	2.5 Y 8/2	.57	Light Yellow Gray	Pinkish Gray	Light Brownish Gray	Very Light Gray	Bluish Gray

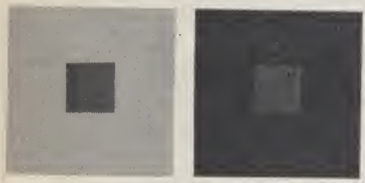
Samples under the five illuminants were compared with identical samples under a Macbeth Daylighting Unit (color temperature 7000°K). "Good Match" indicates that the color of the sample so designated most nearly matched the standard under the Macbeth unit. The footcandle intensity of all illuminants was approximately the same.

The Munsell designations are approximate, and were determined under the Macbeth unit.

* For Standard ICI Illuminant C, representative of average daylight.

Filament lamps, having more energy in the long wavelengths than daylight, and less in the short wavelengths, enhance reds, oranges, and yellows, and subdue blues and greens. However, filament lamps have been in use for so long that these changes have become generally accepted, and are commonly taken for granted. The advent of the fluorescent lamp, with its different spectral energy distribution, has directed increased attention to the question of light-source color. Although the various "white" fluorescent lamps differ considerably in color (see Fluorescent Lamps, Chapter Three), most of them tend to accentuate the blues, greens, and yellows, and to have a graying effect on the reds. Where a color happens to have a high reflectance in the region of one of the blue or yellow-green mercury lines present in the fluorescent lamp spectrum, the effect of fluorescent lighting is often particularly marked. However, the rapidly increasing use of fluorescent lamps over a period of years has had a tendency to accustom people to this new set of color changes, and has done much to bring about their common acceptance. In some applications the effect produced by the closer-to-daylight quality of the fluorescent lamp is definitely preferred.

In choosing wall colors, fabrics, rugs, and other elements of a decorative scheme, it is important that the selection be made under the same type of illumination with which the materials will be used. Since intensity of illumination, as well as spectral quality, influences the appearance of colors, the footcandle level should also approximate the conditions of actual use. High intensities tend to "wash out" colors and make them seem lighter, thus opening the way to erroneous conclusions. Since the eye sees the same colors quite differently in different combinations, variations in background color may be another source of error in judging colors. The variation in apparent value of the same gray, viewed against two different backgrounds, demonstrates an effect that is even more striking in color.



Color is known to have certain psychological effects upon people and their emotions. Blues and greens produce a feeling of coolness and tend to create an illusion of space and distance; on the other hand, reds, oranges and yellows, possibly because they are associated with fire, produce a feeling of warmth, and are what might be called "approaching colors." Even a tinge of blue or yellow in white light makes the light "cool" or "warm." The colors at the red end of the spectrum are said to be exciting and stimulating, while blues, greens and purples are soothing and depressing, and color can often be used in subtle ways to help create a desired atmosphere.

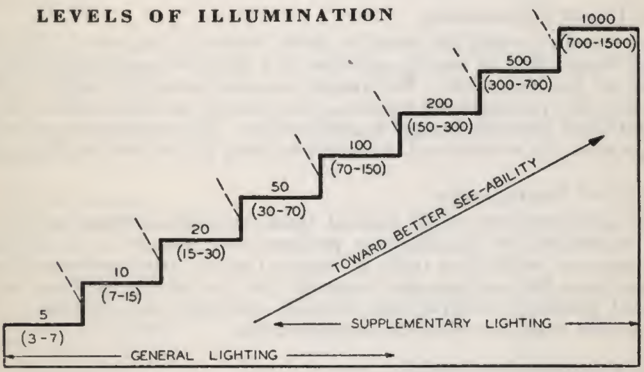
CHAPTER FIVE

ILLUMINATION LEVELS

The high levels of illumination produced by natural daylight are desirable for many seeing tasks. Before the development of modern light sources many severe visual tasks had to be performed in daylight hours because of the low levels of illumination provided by the artificial illuminants then in use. The illumination intensities which were considered to be good practice in past years were largely determined by the light sources then available. Present-day practice recognizes that the footcandle levels now recommended do not represent the ultimate in see-ability. They do, however, represent practical values which may readily be obtained by means of existing light sources and equipment.

The relationship between footcandle levels and ability to see is geometric rather than arithmetic, and the chart below lists approximately equal steps in footcandle effectiveness.

LEVELS OF ILLUMINATION



The quantitative requirement for good illumination of a specific seeing task is primarily a function of the difficulty of the task in terms of fineness of detail, brightness or color contrast, and the speed demanded. Other factors such as the length of time for which the task is to be performed, the surrounding conditions, and the physiological state of the eyes which have to do the work are also involved.

The footcandle table in this chapter is divided into two parts, general interior lighting and floodlighting, and industrial applications. The values of illumination listed are to be provided *on the work surface*, whether it be horizontal, vertical, or oblique. Where there is no definite work area, the plane of reference is assumed to be a horizontal surface 30 inches above the floor. The table is based not on initial illumination from a new, clean, installation, but on *footcandles maintained in service*.

FOOTCANDLE LEVELS FOR SEEING TASKS

Level A—100 Footcandles

For very exacting and prolonged seeing tasks, such as fine bench and machine work, extra fine hand painting and finishing, and for the discrimination of fine detail of low contrast. For showcases, wall cases and open counter displays in stores where importance of detail and attention value are prime factors. (Under various circumstances the footcandles may range from 30% below to 40% above the value given.)

Level B—50 Footcandles

For severe and extensive seeing tasks, such as medium and fine machine work, medium fine assembly and inspection, fine sanding and finishing of woodwork, drafting and proofreading. For general merchandising areas in stores. (Range—minus 30% to plus 40%.)

Level C—20 Footcandles

For moderately critical and lengthy seeing tasks, such as rough bench and machine work, medium assembly and inspection, hand painting and finishing, for pressing light cloth products and weaving light woolens. For circulation areas in stores. (Range—minus 30% to plus 40%.)

Level D—10 Footcandles

For visually controlled work in which seeing is important, but more or less interrupted or casual, and does not involve discrimination of fine details or low contrasts. For rough manufacturing processes, such as moulding clay products and cements, glass blowing machines, billet, blooming and sheet bar mills in steel manufacturing. For stockrooms and active storage areas for a variety of small articles such as for merchandise stocks.

Level E—5 Footcandles

For interiors where crude manual tasks are intermittently carried on, such as required for grinding clay products and cements, stone crushing, hand furnaces and boiling tanks in chemical plants, stockrooms and active storage areas for medium size materials; for the safe assembly or movement of people in auditoriums, through corridors and stairways. For active work areas out-of-doors—loading docks.

Level AA—200 Footcandles

For extra fine inspection, such as required in making jewelry and precision instruments. For featured items and merchandise displays in show windows in secondary business areas of large cities. (Range—minus 30% to plus 40%.)

Level AAA—500 Footcandles

For feature merchandise displays in show windows in main business areas of large cities. For color identification in industry. (Range—minus 30% to plus 40%.)

Level AAAA—1000 Footcandles

Outdoor levels of illumination. For photography, hospital operating rooms, and the daytime illumination of show windows. (Range—minus 30% to plus 40%.)

GENERAL INTERIOR AND FLOODLIGHTING

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Armories—		
Drill	10	D
Exhibitions	30	C
Art Galleries—		
General	10	D
On Paintings	50	B
Auditoriums—		
Assembly Only	10	D
Exhibitions	30	C
Automobile—		
Manufacturing (See Industrial)		
Parking Spaces	2	—
Showrooms (Also See Show Windows)	50	B
Used Car Lots—		
Front Row of Cars	50	B
Remainder of Area	10	D
Badminton	30	C
Banks—		
Lobby	20	C
Cages and Offices	50	B
Barber Shops and Beauty Parlors	50	B
Baseball—		
Seats—		
During Game	2	—
Before and After Game	5	E
Infield—		
Major League	150	A
AA and AAA League	75	A
A and B League	50	B
C and D League	30	C
Semi-Pro League	20	C
Minimum	15	D
Outfield—		
Major League	100	A
AA and AAA League	50	B
A and B League	30	C
C and D League	20	C
Semi-Pro League	15	D
Minimum	10	D
Basketball—		
Recreational	10	D
School	30	C
Bathing Beaches	1	—
Billiards—		
General	10	D
On Tables	50	B

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Bowling—		
General	10	D
On Pins	50	B
On the Green	10	D
Boxing—		
Seats—		
During Bout	2	—
Before and After Bout	5	E
Ring—		
Amateur	100	A
Professional	200	AA
Championship	500	AAA
Building—		
Construction	10	D
Excavation Work	2	—
Building Exteriors and Monuments—		
Bright Surroundings—		
Light Surfaces (80% RF)†	10	D
Medium—Dark Surfaces (40% RF)†	20	C
Dark Surroundings—		
Light Surfaces (80% RF)†	5	E
Medium—Dark Surfaces (40% RF)†	10	D
Bulletin and Poster Boards—		
Bright Surroundings—		
Light Surfaces	50	B
Dark Surfaces	100	A
Dark Surroundings—		
Light Surfaces	20	C
Dark Surfaces	50	B
Churches—		
Auditoriums	5	E
Sunday School Rooms	20	C
Pulpit or Rostrum	20	C
Art Glass Windows—		
Light Color	20	C
Medium Color	100	A
Dark Color	200	AA
Clock Golf	10	D
Club and Lodge Rooms—		
Lounge and Reading Rooms	20	C
Auditoriums	10	D
Coal Yards—Protective	0.2	—
Construction (See Building)		
Court Rooms	20	C
Croquet	10	D
Dance Halls	5	E
Depots (See Transportation)		
Drafting Rooms—		
Prolonged Close Work, Art Drafting and Designing in Detail	50	B

† Approximate reflection factor.

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Dredging	2	—
Drill Fields	5	E
Factories (See Industrial)		
Fire Engine Houses	10	D
Flags—Floodlighted	30	C
Football—		
Professional	100	A
Class A	50	B
Class B	30	C
Class C	20	C
Minimum	10	D
Garages—		
Storage	10	D
Repair and Washing Dept	50	B
Gasoline Service Stations—		
Yard	10	D
Pump Island and Sales Room	30	C
Lube Room—General	20	C
Work Areas, Repair, and Washing	50	B
Lavatories	10	D
Gymnasium—		
Locker and Shower Rooms	10	D
Exercising Room—Fencing, Boxing, Wrestling, Basketball, Volley Ball and Soft Ball—		
General Exercising	20	C
Exhibition Games and Matches	30	C
Handball	30	C
Hangars, Airplane—		
Storage	10	D
Repair and Maintenance	50	B
Homes—		
Dining Room, Living Room, Library, Sun Room, Entrance Hall, Stairways and Landings, Bedrooms and Bathrooms—		
General Illumination	5	E
Reading—Casual Periods	20	C
Reading—Small Type, Prolonged Periods	40	B
Writing	20	C
Children's Study Tables	40	B
Sewing—		
Average for Casual Periods	20	C
Average for Prolonged Periods	40	B
Dark Goods and Fine Needlework	100	A
Mirrors—		
Dressing Table—Light on Face	20	C
Bathroom—Light on Face	40	B
Game Tables—		
Card Tables	10	D
Ping Pong	40	B

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Homes—(Continued)		
Kitchen—		
General Illumination	10	D
Work Counter, Range and Sink	40	B
Laundry—		
Ironer, Ironing Board and Tubs	40	B
Workbench	40	B
Horseshoe Pitching	10	D
Hospitals—		
Corridors	5	E
Laboratories—		
General Laboratory Work	30	C
Close Work	50	B
Lobby and Reception Room	20	C
Operating Room—		
General	50	B
Operating Table—		
Major Operations	1000	AAAA
Minor Operations	200	AA
Private Rooms and Wards	30	C
Hotels—		
Lobby	20	C
Dining Room	5	E
Kitchen	20	C
Guest Rooms, Writing Rooms (See Homes)		
Corridors	5	E
Ice Hockey—		
Outdoor	10	D
Indoor	30	C
Industrial Plants (See Industrial)		
Laundries (See Industrial)		
Library—		
Reading Room	30	C
Stack Room	10	D
Loading Docks	5	E
Lumber Yards	1	—
Machine Shops (See Industrial)		
Monuments (See Building Exteriors)		
Motordromes—		
Seats	2	—
Track	20	C
Museums—		
General	10	D
Special Displays	50	B
Office Buildings—		
Bookkeeping, Typing and Accounting	50	B
Conference Rooms—		
General Meetings	30	C
Office Activities (See Desk Work)		
Corridors and Stairways	5	E

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Office Buildings—(Continued)		
Desk Work—		
Intermittent Reading and Writing	30	C
Prolonged Close Work, Computing, Studying, Designing, Reading Blueprints and Plans	50	B
Filing and Index References	30	C
Lobby	20	C
Mail Sorting	30	C
Reception Rooms	20	C
Stenographic Work—		
Prolonged Reading Shorthand Notes	50	B
Vault	20	C
Piers—		
Freight	5	E
Passenger	5	E
Playgrounds	5	E
Polo	10	D
Post Office—		
Lobby	20	C
Sorting, Mailing, Etc.	30	C
Storage	10	D
File Room	30	C
Corridors and Stairways	5	E
Prison Yards	5	E
Professional Offices—		
Waiting Rooms	20	C
Consultation Rooms	30	C
Examination	100	A
Dental Chairs	200	AA
Protective	0.2	—
Quarries	5	E
Railroad Yards—		
Receiving	0.2	—
Classification	0.3	—
Residences (See Homes)		
Restaurants, Lunch Rooms, Cafeterias—		
Dining Area	10	D
Food Displays	50	B
Kitchens	20	C
Roque	20	C
Schools—		
Auditoriums—		
Assembly Only	10	D
Study Halls	30	C
Class and Study Rooms, Desk and Blackboards	30	C
Corridors and Stairways	5	E
Drawing Room	50	B
Gymnasium—		
General Exercising	20	C
Exhibition Games	30	C

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Schools—(Continued)		
Laboratories—		
General Laboratory Work	30	C
Close Work	50	B
Lecture Rooms—		
General	20	C
Special Exhibits and Demonstrations	50	B
Manual Training—		
General	30	C
Close Work	100	A
Sewing	100	A
Sight-Saving Classes	50	B
Service Space—		
Corridors	5	E
Elevators—Freight and Passenger	10	D
Halls and Stairways	5	E
Storage (See Storage and Stockrooms)		
Toilets and Washrooms	10	D
Shipyards—		
General	5	E
Ways and Fabrication Areas	10	D
Show Windows—		
High Surrounding Brightness Areas—		
General Displays	300	AA
Feature Displays	500	AAA
Lower Surrounding Brightness Areas—		
General Displays	100	A
Feature Displays	200	AA
Minimizing Daylight Reflections	1000	AAAA
Skating Rink (Indoor)	10	D
Skating (Outdoor)	2	—
Smoke Stacks with Advertising Messages	20	C
Softball—		
Infield—		
Class A	50	B
Class B	30	C
Class C	20	C
Minimum	10	D
Outfield—		
Class A	30	C
Class B	20	C
Class C	10	D
Minimum	5	E
Squash Racquets	30	C
Storage Yards (Outdoor)	1	—
Store Interiors (Also See Show Windows)		
Circulation Areas	20	C
General Merchandising Areas	50	B
Showcases, Wall Cases and Open Counter Displays	100	A
Feature Displays	200	AA
Stockrooms	10	D

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Swimming Pools	10	D
Table Tennis—Ping Pong	50	B
Target Shooting (On Target)	50	B
Tennis—		
Recreational	20	C
Exhibition Matches	30	B
Theatres and Motion Picture Houses—		
Auditoriums—		
During Intermission	5	E
During Picture	0.1	—
Foyer	10	D
Lobby	20	C
Toboggan Slides	2	—
Transportation—		
Cars—		
Baggage, Day Coach, Dining, Pullman	30	C
Mail—		
Bag Racks and Letter Cases	30	C
Storage	5	E
Street Railway, Trolley Bus, Motor Bus and Subway Cars	30	C
Depots, Terminals and Stations—		
Waiting Room	20	C
Ticket Offices—		
General	20	C
Ticket Rack and Counters	50	B
Rest Rooms, Smoking Room	20	C
Baggage Checking Office	20	C
Storage	5	E
Concourse	5	E
Platforms	5	E
Toilets and Washrooms	10	D
Trap Shooting (Vertical Surface at 150 ft.)	30	C
Volley Ball—		
Recreational	10	D
Exhibition Matches	20	C
Water Tanks with Advertising Messages	20	C
Woodworking (See Industrial)		

INDUSTRIAL INTERIORS

Airplane Manufacturing—		
Stock Parts—		
Production	50	B
Inspection	100	A
Parts Manufacturing—		
Drilling, Riveting and Screw Fastening	30	B
Spray Booths	30	C

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Airplane Manufacturing—(Continued)		
Sheet Aluminum Layout and Template Work; Shaping and Smoothing of Small Parts for Fuselage, Wing Sections, Cowling, etc.	50	B
Welding—		
General Illumination	20	C
At Work-Point	1000	AAAA
Sub-Assembly—		
Landing Gear, Fuselage, Wing Sections, Cowling and Other Large Units	30	C
Final Assembly—		
Placing of Motors, Propellers, Wing Sections and Landing Gear	30	C
Inspection of Assembled Ship and Its Equipment	50	B
Machine Tool Repairs	100	A
Assembly—		
Rough	20	C
Medium	50	B
Fine	100	A
Extra Fine	200	AA
Automobile Manufacturing—		
Assembly Line	100	A
Frame Assembly	30	C
Body Manufacturing—		
Parts	30	C
Assembly	30	C
Finishing and Inspecting	200	AA
Bakeries	20	C
Book Binding—		
Folding, Assembling, Pasting, etc.	20	C
Cutting, Punching and Stitching	30	C
Embossing	30	C
Breweries—		
Brew House	5	E
Boiling, Keg Washing and Filling	10	D
Bottling	20	C
Building—		
Construction	10	D
Excavation Work	2	—
Candy Making—		
Box Department	20	C
Chocolate Department—		
Husking, Winnowing, Fat Extraction, Crushing and Refining, Feeding	10	D
Bean Cleaning and Sorting, Dipping, Packing, Wrapping	20	C
Milling	50	B
Cream Making—		
Mixing, Cooking and Molding	20	C
Gum Drops and Jellied Forms	20	C
Hand Decorating	50	B

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Candy Making—(Continued)		
Hard Candy—		
Mixing, Cooking and Molding	20	C
Die Cutting and Sorting	50	B
Kiss Making and Wrapping	50	B
Canning and Preserving	20	C
Chemical Works—		
Hand Furnaces, Boiling Tanks, Stationary Driers, Stationary and Cavity Crystallizers	5	E
Mechanical Furnaces, Generators, and Stills, Mechanical Driers, Evaporators, Filtration, Mechanical Crystallizers, Bleaching	10	D
Tanks for Cooking, Extractors, Percolators, Nitrators, Electrolytic Cells	20	C
Clay Products and Cements—		
Grinding, Filter Presses, Kiln Rooms	5	E
Molding, Pressing, Cleaning and Trimming	20	C
Color, Glazing and Enameling	30	C
Cleaning and Pressing Industry—		
Checking and Sorting	20	C
Dry and Wet Cleaning and Steaming	10	D
Inspection and Spotting	200	AA
Pressing—		
Machine	30	C
Hand	50	B
Receiving and Shipping	10	D
Repair and Alteration	200	AA
Cloth Products—		
Cutting, Inspecting, Sewing—		
Light Goods	30	B
Medium Goods	100	A
Dark Goods	200	AA
Pressing, Cloth Treating (Oilcloth, etc.)—		
Light Goods	30	C
Medium Goods	50	B
Dark Goods	100	A
Coal Tipples and Cleaning Plants—		
Breaking, Screening and Cleaning	10	D
Picking	200	AA
Construction—		
General	10	D
Excavation Work	2	—
Dairy Products (See Milk Processing)		
Electrical Equipment Manufacturing—		
Impregnating	30	B
Insulating and Coil Winding	100	A
Testing	50	B
Machining (See Machine Shops)		
Assembling (See Assembly)		
Inspecting (See Inspection)		
Elevators—Freight and Passenger	10	D
Engraving	200	AA

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Explosives—		
Hand Furnaces, Boiling Tanks, Stationary Driers, Stationary and Gravity Crystallizers	5	E
Mechanical Furnaces, Generators and Stills, Mechanical Driers, Evaporators, Filtration, Mechanical Crystallizers	10	D
Tanks for Cooking, Extractors, Percolators, Nitrators	20	C
Forge Shops	10	D
Foundries—		
Changing Floor, Tumbling, Cleaning, Pouring and Shaking Out	5	E
Rough Molding and Core Making	10	D
Fine Molding and Core Making	20	C
Cleaning and Grinding Castings	30	C
Inspecting (See Inspection)		
Garages—		
Storage	10	D
Repair Department and Washing	50	B
Glass Works—		
Mix and Furnace Rooms, Pressing and Lehr, Glass Blowing Machines	10	D
Grinding, Cutting Glass to Size, Silvering	30	C
Fine Grinding and Beveling	50	B
Etching, Decorating, Polishing and Inspecting	100	A
Glove Manufacturing—		
Pressing, Knitting, Sorting—		
Light Goods	20	C
Medium Goods	50	B
Dark Goods	100	A
Cutting, Stitching, Trimming and Inspecting—		
Light Goods	30	B
Medium Goods	100	A
Dark Goods	200	AA
Hangars—		
Storage	10	D
Repair and Maintenance	50	B
Hat Manufacturing—		
Dyeing, Stiffening, Braiding, Cleaning and Refining—		
Light	20	C
Medium	50	B
Dark	100	A
Forming, Sizing, Pouncing, Flanging, Finishing and Ironing—		
Light	30	C
Medium	50	B
Dark	100	A
Sewing—		
Light	30	B
Medium	100	A
Dark	200	AA

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Ice Making—Engine and Compressor Room, Freezing Tank Room	10	D
Inspection—		
Rough	20	C
Medium	50	B
Fine	100	A
Extra Fine	200	AA
Jewelry and Watch Manufacturing	200	AA
Laundries—		
Washing	10	D
Flat Work Ironing, Weighing, Listing and Marking	20	C
Machine and Press Finishing, Sorting	30	C
Fine Hand Ironing	50	B
Leather Manufacturing—		
Vats	5	E
Cleaning, Tanning and Stretching	10	D
Cutting, Fleshing and Stuffing	20	C
Finishing and Scarfing	30	C
Leather Working—		
Pressing, Winding and Glazing—		
Light	30	C
Medium	50	B
Dark	100	A
Grading, Matching, Cutting, Scarfing, Sewing—		
Light	30	B
Medium	100	A
Dark	200	AA
Locker Rooms	10	D
Machine Shops—		
Rough Bench and Machine Work	20	C
Medium Bench and Machine Work, Ordinary Automatic Machines, Rough Grinding, Medium Buffing and Polishing	*30	B
Fine Bench and Machine Work, Fine Automatic Machines, Medium Grinding, Fine Buffing and Polishing	100	A
Extra Fine Bench and Machine Work, Grinding—Fine Work	200	AA
Meat Packing—		
Slaughtering	10	D
Cleaning, Cutting, Cooking, Grinding, Canning, Packing	20	C
Milk Processing—		
Boilers, Bottle Storage, Storage Refrigerators, Weighing Room	10	D
Can Washers, Cooling Equipment, Pasteurizers, Receiving, Separators	20	C

* Large-area light sources of low surface-brightness and good diffusion are necessary for the inspection of shiny or polished work surfaces or parts.

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Milk Processing—(Continued)		
Bottle Sorting	50	B
Bottle Washers	*50	B
Cleaning, Fittings and Pipes	*50	B
Filling and Inspection	50	B
Gauges, Meters, Thermometers, Scales	30	C
Vats	50	B
Milling, Grain Foods—		
Cleaning, Grinding and Rolling	10	D
Baking or Roasting	20	C
Flour Grading	30	C
Offices—		
Bookkeeping, Typing and Accounting	50	B
Conference Room—		
General Meetings	30	C
Office Activities (See Desk Work)		
Corridors and Stairways	5	E
Desk Work—		
Intermittent Reading and Writing	30	C
Prolonged Close Work, Computing, Studying, Designing, Reading Blueprints and Plans	50	B
Filing and Index References	30	B
Lobby	20	C
Mail Sorting	30	C
Reception Rooms	20	C
Stenographic Work—		
Prolonged Reading Shorthand Notes	50	B
Vault	20	C
Packing and Boxing	10	D
Paint Manufacturing—		
General	20	C
Comparing Mix with Standard	100	A
Paint Shops—		
Dipping, Spraying, Firing, Rubbing, Ordinary Hand Painting and Finishing	20	C
Fine Hand Painting and Finishing	50	B
Extra Fine Hand Painting and Finishing (Automobile Bodies, Piano Cabinets, etc.)	100	A
Paper Box Manufacturing—		
Light	20	C
Dark	50	B
Storage	5	E
Paper Manufacturing—		
Acid Towers, Beaters, Deckers, Digester House, Knotters, Drying Cylinders, Calendering, Settling Tank House, Soda Room, Sulphur Room and Pulp Grinding	10	A
Bleachers, Paper Cutters, Layboys, Trimmers, Lappers, Thune Press and Wood Chipping	20	C
Hand Counting, Wet End of Paper Machine	30	C

* Large-area light sources of low surface-brightness and good diffusion are necessary for the inspection of shiny or polished work surfaces or parts.

	Footcandles Maintained in Service (Not Initial Values)	Footcandle Levels (Refer to Figure page 5-1)
Paper Manufacturing—(Continued)		
Paper Machine Reel, Paper Inspection and Laboratories	50	B
Rewinder	100	A
Storage	5	E
Plating	10	D
Power Plants, Engine Room, Boilers—		
Boilers, Coal and Ash Handling, Storage Battery Rooms	5	E
Auxiliary Equipment, Oil Switches, Transformers, Engines, Generators, Blowers, Compressors	20	C
Control Room—		
Switchboards and Meters	30	C
Printing Industries—		
Type Foundries—		
Matrix Making, Dressing Type	100	A
Font Assembly—Sorting	50	B
Hand Casting	30	C
Machine Casting	20	C
Photography—		
Dry Plate and Film	2000	AAAA
Wet Plate	3000	AAAA
Printing on Metal	2000	AAAA
Electrotyping—		
Molding, Routing, Finishing, Leveling Molds	100	A
Trimming	50	B
Blocking, Tinning	30	C
Electroplating, Washing, Backing	20	C
Photoengraving—		
Etching, Staging	20	C
Blocking	30	C
Proofing	50	B
Tint Laying, Routing, Finishing	100	A
Printing Plants—		
Presses	30	C
Imposing Stones	*100	A
Proofreading	100	A
Protective Industrial	0.2	—
Receiving and Shipping	10	D
Rubber Tire and Tube Manufacturing—		
Stock Preparation—		
Plasticating, Milling and Branbury	20	C
Calendering	30	C
Fabric Preparation—Stock Cutting and Bead Building	30	C
Tube and Tread Tubing Machines	20	C
Tire Building—		
Solid Tires	20	C
Pneumatic Tires	50	B

* Large-area light sources of low surface-brightness and good diffusion are necessary for the inspection of shiny or polished work surfaces or parts.

	Footcandles Maintained in Service	Footcandle Levels
Rubber Tire and Tube Manufacturing—(Continued)		
Curing Department—		
Tube and Casing	50	B
Final Inspection—		
Tube	50	B
Casing	100	A
Wrapping	20	C
Warehouse	5	E
Rubber Goods, Mechanical—		
Stock Preparation—		
Plasticating, Milling and Branbury	20	C
Calendering	30	C
Fabric Preparation—Stock Cutting and Hose Looms	30	C
Extruded Products	30	C
Molded Products and Curing	50	B
Inspection	100	A
Boxing	20	C
Warehouse	5	E
Sheet Metal Works—		
Miscellaneous Machines, Medium Bench Work, Punches, Presses, Shears, Stamps, Welders, Spinning	30	C
Tin Plate and Similar Inspection	*50	B
Shipyards—		
General	5	E
Ways and Fabrication Areas	10	D
Shoe Manufacturing (Leather)		
Cutting and Stitching—		
Cutting Tables	20	C
Marking, Buttonholing, Skiving, Sorting, Vamping and Counting—		
Light Materials	20	C
Dark Materials	100	A
Stitching—		
Light Materials	30	B
Dark Materials	200	AA
Making and Finishing—		
Nailers, Sole Layers, Welt Beaters and Scarfers, Trimmers, Welters, Lasters, Edge Setters, Sluggers, Randers, Wheelers, Treers, Cleaning, Spraying, Buffing, Polishing, Embossing—		
Light Materials	20	C
Dark Materials	100	A
Storage, Packing and Shipping	10	D
Shoe Manufacturing (Rubber)		
Washing, Coating, Mill Run Compounding	10	D
Varnishing, Vulcanizing, Calendering, Upper and Sole Cutting	30	C
Sole Rolling, Lining, Making and Finishing Processes	50	B

* Large-area light sources of low surface-brightness and good diffusion are necessary for the inspection of shiny or polished work surfaces or parts.

	Footcandles Maintained in Service	Footcandle Levels
Silk and Rayon Manufacturing—		
Soaking, Fugitive Tinting, and Conditioning or Setting of Twist	10	D
Winding, Twisting, Rewinding and Coning, Quilling, Slashing	30	C
Warping (Silk or Cotton System)—		
On Creel, on Running Ends, on Reel, on Beam, on Warp at Beaming	50	B
Drawing-In—		
On Heddles and on Reed	100	A
Weaving—		
On Heddles and Reeds	10	D
On Warp Back of Harness	20	C
On Woven Cloth	30	C
Soap Manufacturing—		
Kettle Houses, Cutting, Soap Chip and Powder	10	D
Stamping, Wrapping and Packing, Filling and Packing Soap Powder	20	C
Stairways, Corridors and Passageways	5	E
Steel and Iron Manufacturing—		
Billet, Blooming, Sheet Bar, Skelp and Slabbing Mills	10	D
Boiler Room, Power House, Foundry and Furnace Rooms	10	D
Hot Sheet and Hot Strip Mills	10	D
Cold Strip, Pipe, Rail, Rod, Tube, Universal Plate and Wire Drawing	10	D
Merchant and Sheared Plate Mills	20	C
Tin Plate Mills—		
Hot Strip Rolling and Tinning Machine Department	10	D
Cold Strip Rolling	20	C
Inspection—		
Black Plate, Bloom and Billet Chipping	30	C
Tin Plate and Other Bright Surfaces	*50	B
Machine Shops—		
Rough Bench and Machine Work	20	C
Medium Bench and Machine Work	30	B
Fine Work—Buffing, Polishing**	100	A
Extra Fine Work	200	AA
Blacksmith Shop	10	D
Laboratories (Chemical and Physical)	30	C
Carpenter and Pattern Shop (See Woodworking)		
Storage	2	—
Stone Crushing and Screening—		
Belt Conveyor Tubes, Main Line Shafting Space, Chute Rooms, Inside of Bins	5	E
Primary Breaker Room, Auxiliary Breakers—		
Under Bins	5	E
Screens	10	D
Storage Battery Manufacturing—		
Molding of Grids	20	C

* Large-area light sources of low surface-brightness and good diffusion are necessary for the inspection of shiny or polished work surfaces or parts.

	Footcandles Maintained in Service	Footcandle Levels
Storage and Stockrooms—		
Rough Bulky Materials	5	E
Medium	10	D
Fine Material Requiring Care	20	C
Structural Steel Fabrication	10	D
Sugar Refining—		
General	30	C
Color Inspection	100	A
Testing—		
Rough	20	C
Medium	30	B
Extra Fine Instruments, Scales, Etc.	100	A
Textile Mills (Cotton)		
Opening, Mixing, Picking, Carding and Drawing	10	D
Slubbing, Roving, Spinning, Spooling	20	C
Grading	100	A
Warping on Comb	30	C
Beaming and Slashing on Comb—		
Grey Goods	20	C
Denims	100	A
Inspection—		
Grey Goods (Hand Turning)	50	B
Denims (Rapidly Moving)	200	AA
Automatic Tying-In, Weaving	50	B
Drawing-In by Hand	100	A
Tobacco Products—		
Drying, Stripping, General	10	D
Grading and Sorting	100	A
Toilets and Wash Rooms	10	D
Upholstering—		
Automobile, Coach, Furniture	30	C
Warehouse	5	E
Welding—		
General Illumination	20	C
At Work-Point	1000	AAAA
Woodworking—		
Rough Sawing and Bench Work	20	C
Sizing, Planing, Rough Sanding, Medium Machine and Bench Work, Gluing, Veneering, Cooperage	30	C
Fine Bench and Machine Work, Fine Sanding and Finishing	50	B
Woolen Manufacturing—		
Carding, Picking, Washing, Combing, Twisting, Dyeing	10	D
Drawing-In, Warping—		
Light Goods	20	C
Medium Goods	50	B
Dark Goods	100	A
Weaving—		
Light Goods	20	C
Medium Goods	50	B
Dark Goods	100	A
Knitting Machines	20	C

CHAPTER SIX
INTERIOR LIGHTING DESIGN

Introduction

The design of any lighting installation is dependent on many factors, among which is the provision of the proper quantity of illumination. This is accomplished by first analyzing the seeing task and its particular illumination requirements. It then becomes possible to select the most desirable type of lighting equipment and mathematically design the installation.

The quantity of light for an area may be calculated in two ways, the *Lumen Method*, or the *Point-by-Point Method.* The first one provides average footcandle values by the use of a relatively simple formula. Each of the factors employed in the formula must be properly evaluated in order to obtain accurate results.

The second or point-by-point method, while more accurate in some cases, does involve more complex computations. It is ordinarily used only when a relatively few direct-type luminaires are employed.

LUMEN METHOD OF CALCULATION

In using the lumen method to solve a general lighting problem, six key steps should be taken.

Step 1. Determine the required level of illumination.

Handbooks and manuals list many of the more common seeing tasks, together with the quantity of illumination that should be provided for each. They usually represent minimum values which are good present-day practice; the ultimate in seeing-comfort may be many times in excess of these levels.

Step 2. Select the lighting system and luminaires.

Lighting systems are classified as:—

1. *Direct*
2. *Semi-Direct*
3. *General Diffuse or Direct-Indirect*
4. *Semi-Indirect*
5. *Indirect*

Generally, offices are best lighted by an indirect, semi-indirect, or direct-indirect system. Manufacturing areas usually employ a direct system, and merchandising areas may use any system or combination of systems. Choice as to just which of the lighting systems and luminaires best suit a given application will depend upon the seeing tasks to be performed and the characteristics of the area to be illuminated.

Step 3. Determine the coefficient of utilization.

This is merely the ratio of the lumens reaching the working plane to the total lumens generated by the lamps. It is a factor that takes into account the efficiency and distribution of the luminaire, its mounting height, the room proportions, and the reflection factors of walls and ceiling.

In the determination of the coefficient of utilization it is first necessary to select the proper room index. Since painted surfaces of walls and ceiling absorb some light, it can be generally stated that the smaller the room the greater the percentage of lumens lost. This of course varies with the distribution characteristics of the particular luminaire. The light from a direct luminaire is affected less by the size of a room than that from an indirect type. In determining the room index from the table it should be noted that for direct, semi-direct, direct-indirect, and general diffuse equipment *mounting height* is to be used, and for semi-indirect and indirect *ceiling height* should be used.

With the room index noted, the table of coefficients applicable to the particular luminaire should be selected on the basis of similarity of light distribution and efficiency. The coefficient of utilization can then be determined for the room index just found and for the room reflection factors that will be present in the area. The reflection factors used should represent depreciated room surface conditions, since an accumulation of dirt on walls and ceilings reduces the efficiency of any lighting system. It is important, therefore, in estimating in-service footcandles that the original reflection factors of walls and ceilings be reduced in accordance with their anticipated maintenance.

Step 4. Estimate the maintenance factor.

The in-service footcandles which will be produced by any lighting installation are determined by a careful analysis of the conditions under which the system will operate. Up to this point in the problem careful consideration has been given to the determination of proper values of illumination, the system and luminaire to be used, the dimensions and architecture of the area, the reflection factors of walls and ceiling, and the resulting coefficient of utilization. All of this effort at accuracy is wasted if a haphazard factor for maintenance is applied to attain the final in-service footcandle value.

In the operation of any lighting system there are three elements of maintenance which are variables and which affect the amount of light obtained from the system:

(1) Loss of reflected light through accumulation of dirt on walls and ceilings; this was considered in selecting the coefficient of utilization.

(2) Loss through accumulated dirt on reflecting or transmitting surfaces of the luminaire.

(3) Loss in light output of the lamp. At 70 per cent of lamp life a loss of 15 to 30 per cent may normally be expected. This will vary for different types of lamps.

In the following tables maintenance factors covering lamps and luminaires have been suggested for three conditions defined as follows:

Good Maintenance Factor—Where the atmospheric conditions are good luminaires are cleaned frequently, and lamps are replaced systematically.

Medium Maintenance Factor—Where less clean atmospheric conditions exist, luminaire cleaning is fair, and lamps are replaced only after burnout.

Poor Maintenance Factor—Where the atmosphere is quite dirty and equipment is poorly maintained.

The designer must exercise careful judgment both as to the existing and anticipated conditions in order to arrive at a practical maintenance factor.

Step 5. Calculate the number of lamps and luminaires required.

The number of luminaires and lamps can be calculated from the following formulas:

$$\text{Number of Lamps} = \frac{\text{Footcandles x Area}}{\text{Lumens per Lamp x Coefficient of Utilization x Maintenance Factor}}$$

$$\text{Number of Luminaires} = \frac{\text{Number of Lamps}}{\text{Lamps per Luminaire}}$$

Step 6. Determine the location of the luminaires.

Luminaire locations depend on the general architecture, size of bays, type of luminaire, position of previous outlets, etc.

In order to provide even distribution of illumination for an area it is desirable not to exceed certain limitations of "spacing-to-mounting-height" ratios. These values are indicated for the various types of luminaires in the "Spacing Not to Exceed" column of the Coefficient of Utilization tables in this chapter. The spacings shown are maximums, and closer spacings may be necessary, especially when considering one- or two-lamp fluorescent luminaire designs. In order to obtain required levels of illumination with such an arrangement it is sometimes necessary to install continuous rows of fluorescent light sources very close together.

A factor that is frequently overlooked in the consideration of an indirect incandescent system is ceiling brightness. In an attempt to use a minimum number of units, the designer may endeavor to use maximum spacing with high-wattage lamps. This can result in annoying glare from the ceiling, especially if the unit must be close to it. Brightness values for various light sources and surfaces are given in Chapter Four.

Typical Example

As an example of the lumen method of calculation, assume a large general office 60 feet wide by 100 feet long with a 13-foot ceiling. The reflection factor of the ceiling is 85% and the walls 60%, with fair maintenance for both luminaires and room surfaces.

Step 1. From Chapter Five, 50 footcandles are required for critical office work.

Step 2. Fluorescent luminaires (four 40-watt lamps) of the direct-indirect type with ribbed-glass bottom can be used for an installation of this nature.

Step 3. From the table on page 6—4, the room index is B. With this information applied to the table on page 6—14 for this type of luminaire, with depreciated reflection factors of 75% for ceiling and 50% for walls, the coefficient of utilization will be .55.

Step 4. The maintenance factor, also from the table on page 6—14, will be .55.

Step 5. Substituting these values in the basic formula from page 6—5, the light output from a 40-watt White lamp being 2320 lumens,

$$\text{Number of luminaires} = \frac{50 \text{ x } 60 \text{ x } 100}{4 \text{ x } 2320 \text{ x } .55 \text{ x } .55} = 107$$

Step 6. With the spacing-to-mounting-height ratio from the table on page 6—14 as a guide, it would seem that five rows each containing 22 luminaires would be a desirable arrangement.

ROOM INDEX

		CEILING HEIGHT—FEET										
Semi-Indirect and Indirect Lighting.		9 to 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50		
		MOUNTING HEIGHT ABOVE FLOOR—FEET										
Direct, Semi-Direct, General Diffuse, Direct-Indirect Lighting		7 to 7½	8 to 8½	9 to 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50
Room Width (Feet)	Room Length (Feet)	ROOM INDEX										
9 (8½–9)	8–10	H	I	J	J							
	10–14	H	I	I	J							
	14–20	G	H	I	J	J						
	20–30	G	G	H	I	J	J					
	30–42	F	G	H	I	J	J	J				
	42–Up	E	F	G	H	I	J	J				
10 (9½–10½)	10–14	G	H	I	J	J						
	14–20	G	H	I	J	J	J					
	20–30	F	G	H	I	J	J					
	30–42	F	G	G	H	I	J	J				
	42–60	E	F	G	H	I	J	J				
	60–Up	E	F	F	H	H	I	J				
12 (11–12½)	11–14	G	H	I	I	J	J					
	14–20	F	G	H	I	J	J					
	20–30	F	G	G	H	I	J	J				
	30–42	E	F	G	H	I	J	J				
	42–60	E	F	F	G	H	I	J				
	60–Up	E	E	F	G	H	I	J				
14 (13–15½)	13–20	F	G	H	H	I	J	J				
	20–30	E	F	G	H	I	J	J				
	30–42	E	F	F	G	H	I	J	J			
	42–60	E	E	F	F	H	I	J	J	J		
	60–90	D	E	E	F	G	H	J	J	J		
	90–Up	D	E	E	F	F	G	I	J	J		
17 (16–18½)	16–20	E	F	G	H	I	J	J				
	20–30	E	F	F	G	H	I	J				
	30–42	D	E	F	G	H	H	J	J	J		
	42–60	D	E	E	F	G	G	I	J	J	J	
	60–110	D	E	E	F	G	G	I	J	J	J	
	110–Up	C	D	E	E	F	G	H	I	J	J	
20 (19–21½)	19–30	D	E	F	G	H	I	J	J			
	30–42	D	E	E	F	G	H	I	J	J		
	42–60	D	D	E	E	F	G	I	J	J	J	
	60–90	C	D	E	E	F	G	H	J	J	J	
	90–140	C	D	D	E	F	F	H	I	I	J	J
	140–Up	C	D	D	E	F	F	H	H	I	J	J
24 (22–26)	22–30	D	E	E	F	G	H	I	J	J		
	30–42	C	D	E	F	G	G	I	J	J		
	42–60	C	D	D	E	F	G	H	I	J	J	
	60–90	C	D	D	E	F	F	H	I	J	J	J
	90–140	C	C	D	E	E	F	G	H	I	J	J
	140–Up	C	C	D	E	E	F	G	H	I	I	J
30 (27–33)	27–42	C	D	D	E	F	G	H	I	J	J	
	42–60	C	C	D	D	F	F	H	H	I	J	
	60–90	B	C	C	D	E	F	G	H	I	J	J
	90–140	B	C	C	D	E	E	F	G	H	I	J
	140–180	B	C	C	D	E	E	F	G	H	I	J
	180–Up	B	C	C	D	E	E	F	G	H	I	J
36 (34–39)	34–42	B	C	D	E	F	F	H	I	I	J	
	42–60	B	C	C	D	E	F	G	H	I	J	J
	60–90	A	C	C	C	E	E	F	H	H	J	J
	90–140	A	B	C	C	D	E	F	G	H	I	J
	140–200	A	B	C	C	D	E	F	F	G	H	I
	200–Up	A	B	C	C	D	E	F	F	G	H	I
42 (40–45)	40–60	A	B	C	C	E	F	G	H	I	I	J
	60–90	A	B	B	C	D	E	F	G	H	I	J
	90–140	A	B	B	C	D	D	E	F	G	H	J
	140–200	A	A	B	C	D	D	E	F	G	H	I
	200–Up	A	A	B	C	D	D	E	F	F	G	I
50 (46–55)	46–60	A	A	B	C	D	E	F	G	H	I	J
	60–90	A	A	B	C	C	D	F	F	G	H	J
	90–140	A	A	A	C	C	D	E	F	F	G	I
	140–200	A	A	A	C	C	D	E	E	F	G	I
	200–Up	A	A	A	C	C	D	E	E	F	G	H
60 (56–67)	56–90	A	A	A	B	C	D	E	F	G	H	I
	90–140	A	A	A	B	C	C	D	E	F	G	H
	140–200	A	A	A	B	C	C	D	E	E	F	H
	200–Up	A	A	A	B	C	C	D	E	E	F	H
75 (68–90)	68–90	A	A	A	A	B	C	D	E	F	G	I
	90–140	A	A	A	A	B	C	D	E	F	F	H
	140–200	A	A	A	A	B	B	C	D	E	F	G
	200–Up	A	A	A	A	B	B	C	D	E	F	G
90 or more	90–140	A	A	A	A	A	B	C	D	E	F	G
	140–200	A	A	A	A	A	B	C	D	E	F	G
	200–Up	A	A	A	A	A	B	C	C	D	E	F

BASIC FORMULAS

$$\text{Total Lumens} = \frac{\text{Footcandles x Area}}{\text{Coefficient of Utilization x Maintenance Factor}}$$

$$\text{Number of Lamps} = \frac{\text{Footcandles x Area}}{\text{Lumens per Lamp x Coefficient of Utilization x Maintenance Factor}}$$

$$\text{Luminaires} = \frac{\text{Footcandles x Area}}{\text{Lamps per Luminaire x Lumens per Lamp x Coefficient of Utilization x Maintenance Factor}}$$

$$\text{Footcandles} = \frac{\text{Lamp Lumens x Coefficient of Utilization x Maintenance Factor}}{\text{Area}}$$

$$\text{Area per Luminaire} = \frac{\text{Lamps per Luminaire x Lumens per Lamp x Coefficient of Utilization x Maintenance Factor}}{\text{Footcandles}}$$

EXPLANATORY NOTES FOR FOLLOWING TABLES

Coefficient of Utilization Table (Pages 6—6 to 6—16)

The distribution curves for each luminaire are plotted on the basis of maximum candlepower as 100%, the inner curves representing 75%, 50%, and 25% of maximum.

The figures above and below the vertical arrows indicate the percentage of the total lamp lumens directed above and below the horizontal, their sum being the efficiency of the luminaire.

The maintenance factors represent the depreciation in light output of the luminaire due to dirt and the depreciation in light output of the lamp during its life. The following lamp efficiencies at 70% life were used in establishing the values for each luminaire:

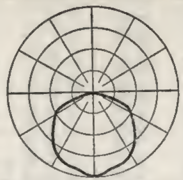
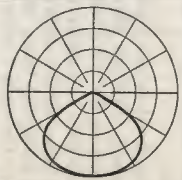
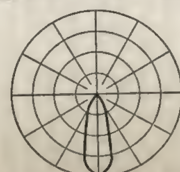
40-Watt Fluorescent	.76	Incandescent	.85
100-Watt Fluorescent	.72	Mercury	.84

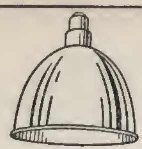
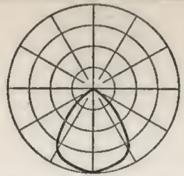
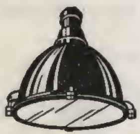
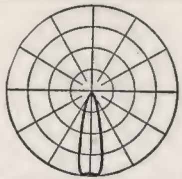
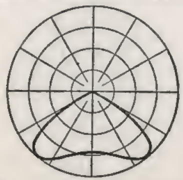
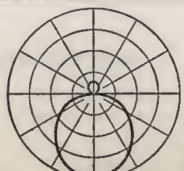
Precalculated Footcandle Table (Pages 6—17 to 6—23)

This table has been developed to minimize the mathematical calculations necessary to determine in-service footcandles. It is possible to read directly the footcandles produced by each 1000 lamp-lumens for the various coefficients of utilization and maintenance factors. For example, a 500-watt luminaire installed on 10-foot by 10-foot spacing with a coefficient of utilization of .46 and a maintenance factor of .60 produces 2.76 footcandles for each 1000 lamp-lumens (page 6—20). Since a 500-watt lamp emits 9950 lumens, 2.76 must be multiplied by 9.95, which gives a value of 27.46 footcandles on the working plane. This table can be used for all types of lamps. The area may be the number of square feet per lamp, per luminaire, per bay, or for small rooms the number of square feet per room.

COEFFICIENTS OF UTILIZATION

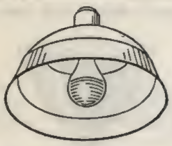
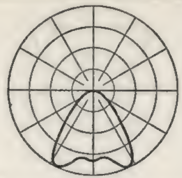
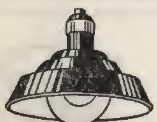
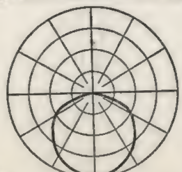
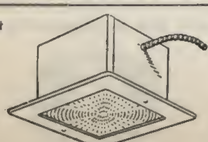
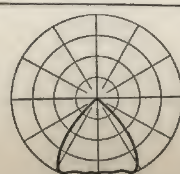
See Note on Page 6—5

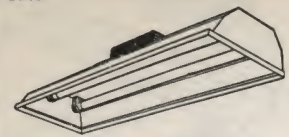
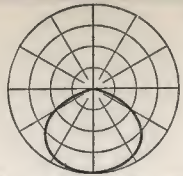
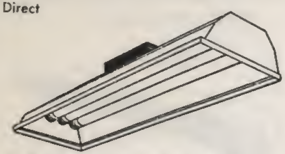
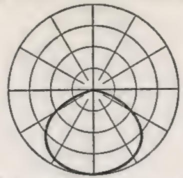
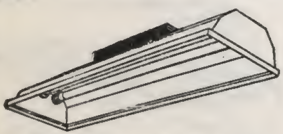
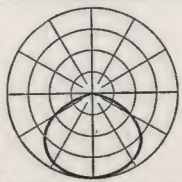
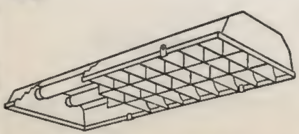
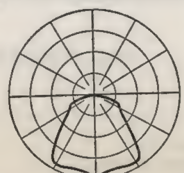
LUMINAIRE	DISTRIBUTION	Spacing Not To Exceed	Maintenance Factor	Ceiling	75%			50%			30%	
				Walls	50%	30%	10%	50%	30%	10%	30%	10%
				Room Index	Coefficients of Utilization							
Direct  RLM Dome Reflector	0 ↑ — ↓ 79 	1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.37	.31	.27	.36	.31	.27	.31	.27
				I	.45	.41	.38	.45	.40	.37	.40	.37
				H	.49	.45	.42	.49	.45	.42	.45	.42
				G	.53	.49	.46	.53	.49	.46	.48	.46
				F	.56	.53	.49	.55	.52	.49	.51	.49
				E	.61	.58	.55	.60	.57	.55	.56	.55
				D	.66	.63	.60	.64	.62	.60	.61	.60
				C	.67	.65	.62	.66	.64	.62	.63	.61
				B	.71	.68	.66	.69	.67	.65	.66	.64
				A	.72	.70	.67	.71	.68	.67	.67	.66
Direct  RLM Deep Bowl	0 ↑ — ↓ 70 	1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.35	.31	.28	.34	.31	.28	.30	.28
				I	.43	.39	.37	.42	.39	.37	.39	.37
				H	.46	.44	.42	.46	.44	.42	.43	.42
				G	.50	.47	.45	.49	.47	.45	.46	.45
				F	.53	.50	.47	.51	.49	.47	.49	.47
				E	.56	.54	.51	.56	.54	.51	.53	.51
				D	.61	.58	.56	.59	.57	.56	.56	.56
				C	.62	.60	.57	.61	.58	.57	.58	.56
				B	.64	.62	.61	.63	.61	.60	.60	.59
				A	.65	.63	.61	.64	.62	.61	.61	.60
Direct  High Bay — Narrow Spread	0 ↑ — ↓ 75 	0.6 x Mounting Height	Good .75 Med. .60 Poor .40	J	.43	.40	.39	.42	.40	.39	.40	.38
				I	.51	.50	.49	.50	.49	.48	.49	.46
				H	.55	.54	.53	.54	.53	.52	.53	.52
				G	.59	.58	.57	.58	.56	.55	.56	.55
				F	.61	.60	.58	.59	.58	.58	.58	.57
				E	.64	.63	.62	.63	.62	.61	.61	.60
				D	.68	.65	.64	.66	.65	.64	.64	.63
				C	.69	.67	.65	.67	.66	.64	.64	.64
				B	.70	.68	.67	.68	.67	.66	.66	.65
				A	.71	.70	.68	.69	.67	.67	.67	.66

Direct  High Bay — Medium or Wide Spread.	0 ↑ — ↓ 75		1.0 x Mounting Height	Good .75 Med. .65 Poor .50	J	.40	.36	.34	.39	.36	.34	.36	.33
					I	.48	.45	.43	.47	.44	.43	.44	.42
					H	.52	.50	.48	.51	.49	.47	.49	.47
					G	.55	.53	.52	.55	.52	.51	.52	.51
					F	.58	.56	.53	.56	.55	.53	.55	.53
					E	.62	.60	.58	.61	.59	.57	.58	.57
					D	.66	.63	.61	.64	.62	.61	.62	.61
					C	.67	.65	.62	.66	.64	.62	.63	.62
					B	.69	.67	.66	.67	.65	.64	.65	.64
					A	.70	.68	.67	.69	.67	.65	.66	.64
Direct  Heavy Duty — Narrow or Medium Spread	0 ↑ — ↓ 70		Narrow Spread 0.5 x Mounting Height / Medium Spread 0.8 x Mounting Height	Good .80 Med. .72 Poor .65	J	.40	.38	.36	.39	.38	.36	.38	.36
					I	.48	.46	.45	.47	.46	.45	.45	.43
					H	.52	.51	.50	.51	.50	.49	.50	.48
					G	.55	.54	.53	.54	.53	.52	.53	.51
					F	.57	.56	.55	.56	.55	.54	.55	.53
					E	.60	.59	.58	.59	.58	.57	.57	.56
					D	.64	.61	.60	.62	.60	.59	.60	.59
					C	.64	.63	.61	.63	.62	.60	.60	.60
					B	.65	.64	.63	.64	.63	.62	.62	.61
					A	.66	.65	.64	.64	.63	.62	.62	.62
Direct  Heavy Duty — Wide Spread	0 ↑ — ↓ 70		1.1 x Mounting Height	Good .80 Med. .72 Poor .65	J	.37	.34	.31	.36	.34	.31	.34	.31
					I	.45	.42	.41	.44	.41	.40	.41	.39
					H	.48	.46	.45	.49	.45	.44	.45	.44
					G	.52	.50	.48	.51	.49	.48	.49	.48
					F	.55	.52	.51	.54	.51	.50	.51	.50
					E	.57	.56	.54	.57	.55	.53	.55	.53
					D	.62	.59	.57	.60	.58	.57	.57	.56
					C	.63	.61	.58	.62	.59	.58	.59	.58
					B	.64	.62	.61	.63	.61	.60	.60	.59
					A	.66	.64	.62	.64	.62	.61	.62	.60
Direct  RLM Glassteel Diffuser	5 ↑ — ↓ 58		1.0 x Mounting Height	Good. 70 Med. .60 Poor .45	J	.27	.23	.20	.26	.23	.20	.22	.20
					I	.34	.30	.28	.33	.29	.27	.29	.27
					H	.37	.34	.31	.36	.33	.31	.32	.30
					G	.40	.37	.34	.39	.36	.34	.35	.33
					F	.42	.39	.37	.40	.38	.36	.37	.36
					E	.46	.43	.41	.45	.42	.40	.41	.40
					D	.49	.47	.44	.48	.46	.44	.44	.43
					C	.51	.49	.46	.49	.47	.46	.46	.44
					B	.53	.51	.49	.51	.49	.48	.48	.47
					A	.54	.53	.51	.53	.51	.49	.49	.48

COEFFICIENTS OF UTILIZATION

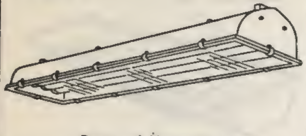
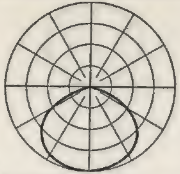
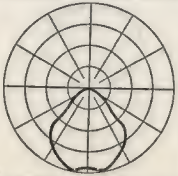
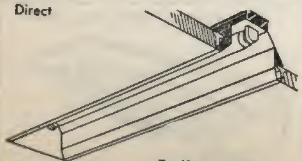
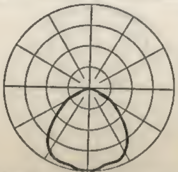
See Note on Page 6—5

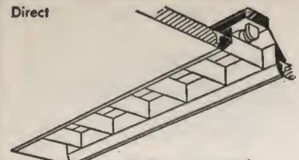
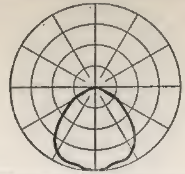
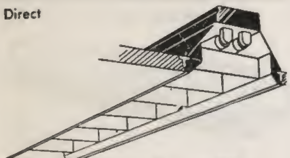
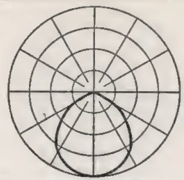
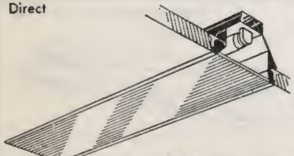
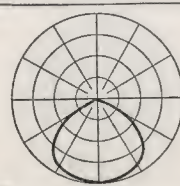
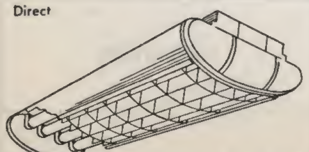
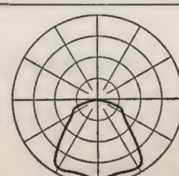
LUMINAIRE	DISTRIBUTION		Spacing Not To Exceed	Maintenance Factor	Ceiling	75%			50%			30%	
					Walls	50%	30%	10%	50%	30%	10%	30%	10%
					Room Index	Coefficients of Utilization							
Direct  RLM Silvered Bowl Diffuser	0 ↑ — ↓ 67		0.8 x Mounting Height	Good .60 Med. .50 Poor .40	J	.38	.36	.35	.38	.36	.35	.38	.35
					I	.46	.45	.44	.45	.44	.43	.44	.42
					H	.49	.49	.48	.49	.48	.47	.48	.47
					G	.53	.52	.51	.52	.51	.50	.51	.49
					F	.55	.54	.53	.53	.53	.52	.53	.51
					E	.57	.57	.56	.57	.56	.55	.55	.54
					D	.61	.59	.58	.59	.58	.57	.57	.56
					C	.62	.61	.59	.60	.59	.58	.58	.57
					B	.63	.62	.61	.61	.60	.59	.59	.58
					A	.64	.63	.62	.62	.61	.60	.60	.59
Direct  Vapor Tight — Wide Spread	0 ↑ — ↓ 65		1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.31	.26	.23	.30	.26	.23	.26	.23
					I	.38	.34	.31	.37	.33	.31	.33	.31
					H	.41	.38	.34	.41	.38	.34	.37	.34
					G	.45	.41	.39	.44	.41	.39	.40	.39
					F	.47	.44	.41	.46	.43	.41	.43	.41
					E	.51	.48	.46	.50	.48	.46	.47	.46
					D	.55	.52	.50	.54	.52	.50	.51	.50
					C	.56	.54	.52	.55	.53	.52	.52	.51
					B	.59	.57	.55	.58	.56	.54	.55	.54
					A	.60	.58	.56	.59	.57	.56	.56	.55
Direct  Prismatic Lens — Medium Spread	0 ↑ — ↓ 53		0.8 x Mounting Height	Good .70 Med. .60 Poor .50	J	.25	.22	.20	.24	.22	.20	.22	.20
					I	.31	.28	.26	.29	.28	.26	.28	.26
					H	.34	.31	.29	.32	.31	.29	.30	.28
					G	.36	.33	.32	.34	.33	.31	.32	.30
					F	.38	.35	.34	.36	.34	.33	.34	.32
					E	.40	.39	.38	.39	.37	.36	.37	.35
					D	.43	.41	.40	.42	.40	.39	.39	.38
					C	.45	.43	.42	.44	.41	.40	.40	.40
					B	.48	.45	.44	.47	.43	.42	.42	.41
					A	.50	.47	.46	.48	.46	.45	.45	.44

Direct  RLM Fluorescent — 40 Watt Lamps	0 ↑ — ↓ 79 	1.0 x Mounting Height	Good .65 Med. .55 Poor .45	J	.38	.32	.28	.37	.32	.28	.31	.28
				I	.47	.42	.39	.46	.41	.38	.40	.37
				H	.51	.47	.44	.50	.47	.43	.46	.43
				G	.55	.51	.48	.54	.51	.47	.50	.47
				F	.58	.54	.51	.57	.53	.51	.52	.50
				E	.63	.60	.57	.62	.59	.56	.58	.55
				D	.68	.64	.61	.66	.64	.61	.63	.60
				C	.70	.67	.63	.68	.65	.64	.64	.62
				B	.73	.70	.68	.71	.68	.67	.67	.66
				A	.74	.72	.70	.72	.70	.68	.69	.67
Direct  RLM Fluorescent — 40 Watt Lamps	0 ↑ — ↓ 72 	1.0 x Mounting Height	Good .65 Med. .55 Poor .45	J	.34	.29	.25	.33	.29	.25	.28	.25
				I	.42	.38	.35	.41	.37	.34	.37	.34
				H	.46	.42	.39	.44	.42	.39	.41	.39
				G	.50	.46	.43	.48	.45	.41	.44	.41
				F	.53	.49	.46	.51	.47	.44	.47	.44
				E	.57	.54	.51	.56	.52	.50	.52	.50
				D	.61	.58	.55	.59	.56	.54	.56	.54
				C	.63	.60	.57	.61	.58	.56	.58	.56
				B	.66	.64	.61	.64	.60	.59	.60	.59
				A	.67	.65	.62	.66	.62	.61	.62	.60
Direct  RLM Fluorescent — 100 Watt Lamps	0 ↑ — ↓ 71 	1.0 x Mounting Height	Good .60 Med. .50 Poor .45	J	.33	.28	.25	.33	.28	.25	.28	.25
				I	.41	.37	.34	.40	.36	.33	.36	.33
				H	.45	.41	.38	.44	.41	.38	.40	.38
				G	.48	.45	.42	.48	.45	.42	.43	.42
				F	.51	.48	.45	.50	.47	.45	.46	.45
				E	.55	.53	.50	.55	.52	.50	.51	.50
				D	.60	.57	.54	.58	.56	.54	.55	.54
				C	.61	.59	.56	.60	.57	.56	.57	.55
				B	.64	.62	.60	.62	.60	.59	.60	.58
				A	.65	.63	.61	.64	.62	.60	.61	.60
Direct  RLM Fluorescent — Louvered	0 ↑ — ↓ 64 	0.9 x Mounting Height	Good .65 Med. .55 Poor .45	J	.33	.28	.26	.32	.28	.26	.28	.26
				I	.39	.36	.34	.39	.35	.34	.35	.34
				H	.43	.40	.38	.42	.40	.38	.39	.38
				G	.46	.43	.41	.45	.43	.41	.42	.41
				F	.48	.46	.43	.47	.45	.43	.45	.43
				E	.52	.50	.47	.51	.49	.47	.48	.47
				D	.55	.53	.51	.54	.52	.51	.52	.51
				C	.57	.55	.52	.56	.53	.52	.53	.52
				B	.59	.57	.56	.57	.56	.55	.55	.54
				A	.60	.58	.56	.59	.57	.56	.56	.55

COEFFICIENTS OF UTILIZATION

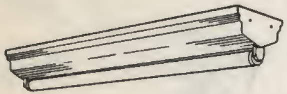
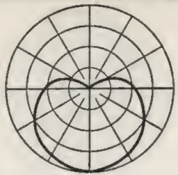
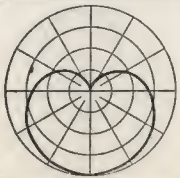
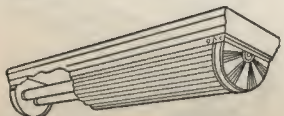
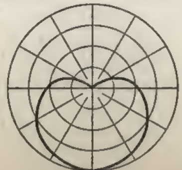
See Note on Page 6—5

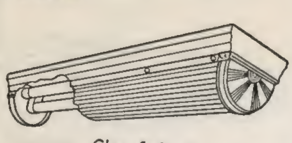
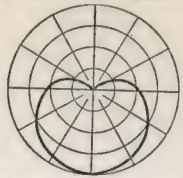
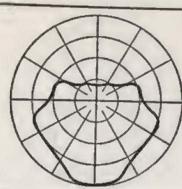
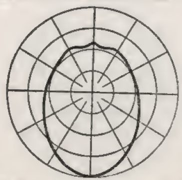
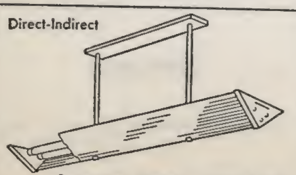
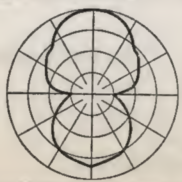
LUMINAIRE	DISTRIBUTION	Spacing Not To Exceed	Maintenance Factor	Ceiling	75%			50%			30%	
				Walls	50%	30%	10%	50%	30%	10%	30%	10%
				Room Index	Coefficients of Utilization							
Direct  Dust and Vapor Tight	0 ↑ — ↓ 60 	1.0 x Mounting Height	Good .70 Med. .65 Poor .55	J	.29	.26	.23	.28	.26	.23	.25	.23
				I	.35	.32	.31	.35	.32	.30	.32	.30
				H	.38	.36	.34	.38	.36	.34	.35	.34
				G	.41	.39	.37	.41	.39	.37	.38	.37
				F	.44	.41	.39	.42	.41	.39	.40	.39
				E	.46	.45	.42	.46	.44	.42	.44	.42
				D	.50	.48	.46	.49	.47	.46	.46	.46
				C	.51	.49	.47	.50	.48	.47	.48	.46
				B	.53	.51	.50	.52	.50	.49	.49	.49
				A	.54	.52	.50	.53	.51	.50	.50	.49
Direct  3 KW Mercury	0 ↑ — ↓ 80 	1.0 x Mounting Height	Good .70 Med. .60 Poor .50	J	.38	.32	.28	.37	.32	.28	.31	.28
				I	.47	.42	.39	.46	.41	.38	.41	.38
				H	.51	.47	.43	.50	.47	.43	.46	.43
				G	.55	.51	.47	.54	.51	.47	.49	.47
				F	.58	.54	.51	.56	.53	.51	.52	.51
				E	.63	.59	.56	.62	.59	.56	.58	.56
				D	.67	.64	.61	.66	.63	.61	.63	.61
				C	.69	.67	.64	.67	.65	.63	.64	.63
				B	.72	.70	.67	.71	.68	.67	.67	.66
				A	.74	.71	.69	.72	.70	.68	.69	.67
Direct  Troffer — Open	0 ↑ — ↓ 80 	0.8 x Mounting Height	Good .70 Med. .60 Poor .55	J	.40	.35	.32	.39	.35	.32	.34	.32
				I	.49	.45	.42	.48	.44	.41	.44	.41
				H	.53	.49	.47	.52	.49	.47	.49	.47
				G	.57	.53	.51	.56	.53	.51	.52	.51
				F	.60	.57	.53	.58	.56	.53	.55	.53
				E	.64	.61	.58	.63	.61	.58	.60	.58
				D	.68	.65	.63	.67	.64	.63	.64	.63
				C	.70	.68	.64	.68	.66	.64	.65	.64
				B	.72	.70	.68	.71	.68	.68	.68	.67
				A	.74	.72	.69	.72	.70	.68	.69	.68

Luminaire	Distribution	Curve	Spacing	Maintenance	Room								
Direct  Troffer — Louvered	0 ↑ — ↓ 65		0.8 x Mounting Height	Good .70 Med. .60 Poor .55	J	.36	.33	.31	.36	.33	.31	.33	.30
					I	.44	.41	.40	.43	.40	.39	.40	.38
					H	.47	.45	.44	.47	.44	.43	.44	.43
					G	.51	.49	.47	.50	.48	.47	.47	.47
					F	.53	.51	.49	.51	.50	.49	.50	.49
					E	.56	.55	.53	.55	.54	.52	.53	.52
					D	.60	.57	.56	.59	.57	.55	.56	.55
					C	.62	.60	.57	.60	.58	.57	.57	.56
					B	.63	.61	.60	.62	.60	.59	.59	.58
					A	.64	.62	.61	.63	.61	.60	.60	.59
Direct  Troffer — Louvered	0 ↑ — ↓ 60		0.8 x Mounting Height	Good .70 Med. .60 Poor .55	J	.34	.31	.28	.29	.31	.30	.32	.29
					I	.40	.39	.38	.40	.38	.37	.38	.36
					H	.43	.42	.42	.43	.42	.41	.42	.40
					G	.47	.45	.45	.46	.45	.43	.44	.43
					F	.49	.48	.46	.47	.47	.45	.47	.45
					E	.51	.51	.49	.51	.50	.48	.49	.48
					D	.55	.53	.51	.53	.52	.51	.51	.51
					C	.56	.54	.52	.54	.53	.52	.52	.51
					B	.57	.55	.54	.56	.54	.53	.53	.53
					A	.58	.56	.55	.56	.55	.54	.54	.53
Direct  Troffer — Ribbed Glass Cover	0 ↑ — ↓ 55		1.0 x Mounting Height	Good .70 Med. .60 Poor .50	J	.28	.24	.22	.27	.24	.22	.24	.22
					I	.34	.31	.29	.33	.30	.29	.30	.29
					H	.37	.34	.33	.36	.34	.32	.33	.32
					G	.39	.37	.36	.38	.37	.35	.38	.37
					F	.42	.39	.37	.40	.38	.37	.41	.40
					E	.44	.43	.40	.43	.42	.40	.42	.41
					D	.47	.45	.43	.46	.45	.43	.44	.43
					C	.49	.47	.45	.47	.46	.45	.45	.44
					B	.50	.48	.47	.49	.47	.46	.46	.45
					A	.51	.50	.48	.50	.48	.47	.47	.46
Direct  Louvered Bottom — Plastic Sides	0 ↑ — ↓ 60		1.0 x Mounting Height	Good .70 Med. .60 Poor .55	J	.29	.26	.23	.28	.26	.23	.25	.23
					I	.35	.32	.31	.35	.32	.30	.32	.30
					H	.38	.36	.34	.38	.36	.34	.35	.34
					G	.41	.39	.37	.41	.39	.37	.38	.37
					F	.44	.41	.39	.42	.41	.39	.40	.39
					E	.46	.45	.42	.46	.44	.42	.44	.42
					D	.50	.48	.46	.49	.47	.46	.46	.46
					C	.51	.49	.47	.50	.48	.47	.48	.46
					B	.53	.51	.50	.52	.50	.49	.49	.49
					A	.54	.52	.50	.53	.51	.50	.50	.49

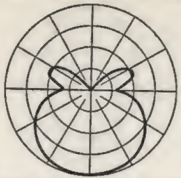
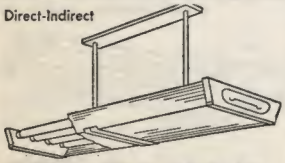
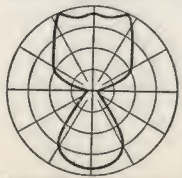
COEFFICIENTS OF UTILIZATION

See Note on Page 6—5

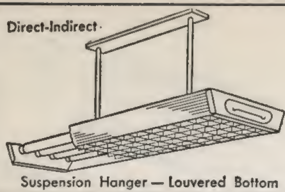
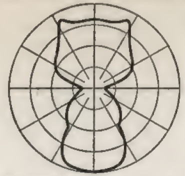
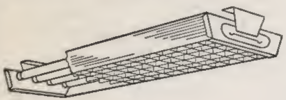
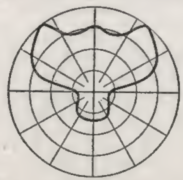
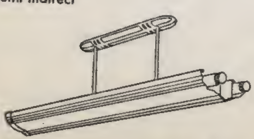
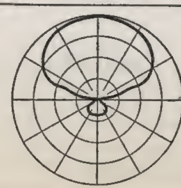
LUMINAIRE	DISTRIBUTION	Spacing Not To Exceed	Maintenance Factor	Ceiling	75%			50%			30%	
				Walls	50%	30%	10%	50%	30%	10%	30%	10%
				Room Index	Coefficients of Utilization							
Direct  Exposed Lamp	8 ↑ — ↓ 77 	1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.32	.27	.23	.32	.26	.23	.25	.23
				I	.40	.35	.31	.39	.34	.30	.34	.30
				H	.44	.39	.36	.43	.39	.35	.36	.35
				G	.48	.43	.40	.46	.42	.39	.41	.39
				F	.52	.47	.43	.50	.46	.42	.45	.42
				E	.57	.52	.48	.55	.51	.47	.50	.46
				D	.62	.56	.52	.59	.55	.51	.54	.51
				C	.65	.59	.54	.62	.57	.54	.56	.53
				B	.69	.63	.59	.65	.61	.58	.60	.58
				A	.71	.66	.62	.67	.63	.60	.61	.60
Semi-Direct  Glass Enclosed	18 ↑ — ↓ 53 	1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.23	.19	.17	.23	.18	.16	.17	.16
				I	.29	.25	.22	.28	.24	.21	.23	.21
				H	.32	.28	.25	.31	.28	.25	.26	.24
				G	.36	.32	.29	.34	.30	.27	.29	.26
				F	.40	.35	.31	.37	.33	.30	.31	.29
				E	.43	.39	.35	.41	.37	.34	.35	.32
				D	.47	.42	.39	.44	.40	.37	.38	.36
				C	.49	.45	.41	.46	.42	.39	.40	.38
				B	.52	.48	.45	.49	.45	.43	.43	.41
				A	.54	.51	.47	.51	.47	.45	.44	.43
Semi-Direct  Glass Enclosed	9 ↑ — ↓ 55 	1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.24	.20	.19	.23	.20	.17	.19	.17
				I	.30	.26	.23	.29	.25	.23	.25	.23
				H	.33	.29	.27	.32	.29	.26	.28	.26
				G	.36	.32	.30	.34	.32	.29	.30	.29
				F	.39	.35	.32	.37	.34	.31	.33	.31
				E	.42	.39	.35	.41	.38	.35	.36	.34
				D	.45	.42	.39	.44	.41	.38	.40	.38
				C	.47	.44	.41	.45	.42	.40	.41	.39
				B	.50	.47	.44	.48	.45	.43	.44	.42
				A	.52	.49	.46	.50	.47	.45	.45	.44

Luminaire	Distribution	Candlepower	Spacing	Maintenance	Room Index								
Semi-Direct  Glass Enclosed	8 ↑ — ↓ 50		1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.21	.17	.14	.20	.16	.14	.16	.14
					I	.26	.22	.20	.25	.21	.19	.21	.19
					H	.29	.25	.23	.28	.25	.22	.24	.22
					G	.32	.28	.25	.30	.27	.25	.26	.24
					F	.34	.30	.27	.33	.30	.27	.29	.27
					E	.38	.34	.31	.36	.33	.31	.32	.30
					D	.41	.37	.34	.39	.36	.34	.35	.33
					C	.42	.39	.36	.41	.38	.36	.37	.35
					B	.45	.42	.39	.42	.40	.39	.39	.38
					A	.47	.44	.41	.45	.42	.40	.41	.39
Semi-Direct  Exposed Lamp	25 ↑ — ↓ 60		1.0 x Mounting Height	Good .75 Med. .65 Poor .55	J	.27	.25	.19	.26	.22	.19	.20	.18
					I	.35	.29	.26	.33	.28	.25	.27	.24
					H	.38	.34	.30	.36	.32	.29	.30	.28
					G	.43	.38	.34	.40	.36	.32	.33	.31
					F	.46	.41	.37	.43	.39	.35	.37	.33
					E	.50	.46	.42	.47	.43	.40	.40	.38
					D	.55	.50	.46	.51	.47	.44	.44	.42
					C	.58	.53	.49	.53	.49	.46	.46	.44
					B	.62	.57	.53	.57	.53	.51	.50	.48
					A	.64	.60	.56	.59	.55	.52	.51	.49
General Diffuse  Enclosing Globe	39 ↑ — ↓ 45		1.2 x Mounting Height	Good .75 Med. .70 Poor .65	J	.24	.19	.16	.22	.18	.15	.16	.14
					I	.29	.25	.22	.27	.23	.20	.21	.19
					H	.33	.28	.26	.30	.26	.24	.24	.21
					G	.37	.32	.29	.33	.29	.26	.26	.24
					F	.40	.36	.31	.36	.32	.29	.29	.26
					E	.45	.40	.36	.40	.36	.33	.32	.29
					D	.48	.43	.39	.43	.39	.36	.34	.33
					C	.51	.46	.42	.45	.41	.38	.37	.34
					B	.55	.50	.47	.49	.45	.42	.40	.38
					A	.57	.53	.49	.51	.47	.44	.41	.40
Direct-Indirect  Suspension Hanger — Glass Panels	47 ↑ — ↓ 36		1.2 x Mounting Height	Good .70 Med. .60 Poor .50	J	.26	.21	.18	.22	.19	.16	.16	.15
					I	.31	.26	.24	.27	.24	.22	.21	.19
					H	.34	.30	.28	.30	.27	.25	.24	.22
					G	.38	.34	.31	.34	.30	.28	.26	.25
					F	.41	.37	.33	.36	.33	.30	.28	.27
					E	.45	.41	.38	.40	.36	.34	.31	.30
					D	.49	.45	.42	.42	.41	.37	.34	.33
					C	.51	.48	.44	.44	.44	.39	.36	.34
					B	.55	.51	.49	.47	.45	.43	.38	.37
					A	.57	.53	.51	.49	.46	.44	.40	.38

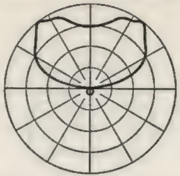
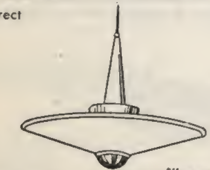
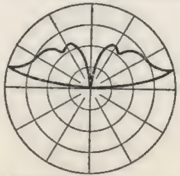
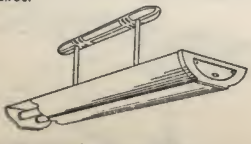
COEFFICIENTS OF UTILIZATION
See Note on Page 6—5

LUMINAIRE	DISTRIBUTION		Spacing Not To Exceed	Maintenance Factor	Ceiling	75%			50%			30%	
					Walls	50%	30%	10%	50%	30%	10%	30%	10%
					Room Index	Coefficients of Utilization							
Semi-Direct  Ceiling Hanger — Glass Panels	18 ↑ — ↓ 49		1.0 x Mounting Height	Good .70 Med. .60 Poor .50	J	.24	.20	.17	.23	.19	.16	.18	.16
					I	.30	.26	.23	.28	.24	.22	.24	.21
					H	.33	.29	.27	.31	.28	.26	.27	.25
					G	.36	.32	.29	.34	.31	.28	.29	.27
					F	.39	.35	.32	.36	.33	.31	.31	.30
					E	.42	.39	.36	.40	.37	.35	.35	.33
					D	.46	.43	.40	.43	.40	.38	.38	.37
					C	.48	.45	.42	.44	.42	.40	.40	.38
					B	.51	.48	.45	.47	.45	.43	.42	.41
					A	.52	.50	.47	.49	.46	.45	.43	.42
Direct-Indirect  Suspension Hanger — Ribbed Glass	46 ↑ — ↓ 33		1.2 x Mounting Height	Good .65 Med. .55 Poor .50	J	.27	.24	.22	.24	.22	.21	.21	.19
					I	.33	.30	.29	.29	.27	.26	.25	.23
					H	.36	.34	.32	.32	.30	.29	.28	.26
					G	.39	.37	.35	.36	.33	.32	.30	.28
					F	.43	.40	.37	.38	.35	.34	.31	.30
					E	.46	.43	.41	.41	.38	.37	.34	.32
					D	.50	.46	.44	.43	.41	.39	.36	.35
					C	.52	.49	.46	.45	.43	.41	.37	.36
					B	.55	.52	.50	.47	.45	.44	.38	.37
					A	.56	.54	.52	.49	.47	.45	.40	.38
Semi-Direct  Ceiling Hanger — Ribbed Glass	14 ↑ — ↓ 45		0.9 x Mounting Height	Good .65 Med. .55 Poor .50	J	.25	.21	.19	.22	.20	.19	.18	.17
					I	.30	.28	.27	.27	.25	.24	.22	.21
					H	.33	.31	.30	.29	.27	.26	.25	.24
					G	.36	.34	.32	.31	.30	.28	.26	.26
					F	.38	.36	.34	.33	.31	.30	.28	.27
					E	.40	.39	.37	.35	.34	.32	.31	.29
					D	.43	.41	.39	.37	.36	.34	.32	.31
					C	.45	.43	.40	.39	.37	.36	.33	.32
					B	.47	.44	.43	.40	.38	.37	.34	.33
					A	.48	.46	.44	.41	.39	.38	.35	.34

COEFFICIENTS OF UTILIZATION

Direct-Indirect  Suspension Hanger — Louvered Bottom	45 ↑ — ↓ 34		1.2 x Mounting Height	Good .70 Med. .65 Poor .60	J	.26	.23	.20	.23	.21	.19	.19	.17
					I	.31	.28	.27	.28	.26	.24	.23	.20
					H	.35	.32	.30	.31	.28	.27	.26	.24
					G	.38	.35	.33	.34	.31	.30	.28	.27
					F	.41	.38	.35	.36	.34	.32	.30	.28
					E	.44	.42	.39	.39	.37	.35	.32	.31
					D	.48	.45	.42	.42	.39	.38	.34	.33
					C	.50	.49	.44	.43	.41	.39	.35	.34
					B	.53	.50	.48	.46	.43	.42	.37	.36
					A	.54	.52	.50	.47	.45	.43	.39	.37
Semi-Direct  Ceiling Hanger — Louvered Bottom	15 ↑ — ↓ 45		0.9 x Mounting Height	Good .70 Med. .65 Poor .60	J	.24	.21	.19	.21	.19	.18	.19	.17
					I	.30	.27	.25	.26	.24	.23	.23	.21
					H	.32	.30	.28	.29	.27	.25	.25	.24
					G	.35	.33	.31	.31	.29	.28	.27	.26
					F	.38	.35	.32	.32	.31	.29	.29	.27
					E	.40	.38	.36	.35	.35	.32	.31	.29
					D	.43	.40	.39	.38	.36	.34	.32	.32
					C	.45	.42	.40	.39	.37	.35	.33	.32
					B	.47	.45	.43	.41	.39	.38	.34	.34
					A	.48	.46	.44	.42	.40	.38	.35	.34
Semi-Indirect  Enclosing Globe — Clear Top	66 ↑ — ↓ 20		1.2 x Ceiling Height	Good .70 Med. .65 Poor .60	J	.20	.16	.13	.16	.13	.11	.10	.09
					I	.24	.20	.18	.20	.17	.15	.13	.12
					H	.28	.24	.21	.23	.19	.17	.15	.13
					G	.31	.27	.24	.26	.22	.20	.17	.15
					F	.34	.30	.27	.28	.24	.22	.19	.17
					E	.38	.34	.31	.31	.27	.25	.21	.19
					D	.42	.38	.35	.34	.30	.28	.23	.22
					C	.45	.41	.37	.36	.32	.30	.25	.23
					B	.49	.45	.42	.39	.36	.34	.27	.25
					A	.51	.47	.44	.41	.38	.36	.28	.27
Semi-Indirect  Glass or Plastic	70 ↑ — ↓ 11		1.2 x Ceiling Height	Good .60 Med. .50 Poor .40	J	.18	.14	.12	.14	.11	.09	.08	.07
					I	.22	.19	.17	.17	.15	.13	.10	.09
					H	.26	.22	.19	.20	.17	.15	.12	.10
					G	.29	.25	.22	.22	.19	.17	.14	.12
					F	.32	.28	.25	.24	.21	.19	.15	.14
					E	.35	.32	.29	.27	.24	.21	.17	.15
					D	.39	.35	.32	.29	.26	.24	.19	.18
					C	.42	.38	.35	.31	.28	.27	.20	.19
					B	.46	.42	.39	.34	.31	.29	.22	.21
					A	.48	.44	.42	.36	.33	.31	.23	.22

COEFFICIENTS OF UTILIZATION
See Note on Page 6—5

LUMINAIRE	DISTRIBUTION	Spacing Not To Exceed	Maintenance Factor	Ceiling	75%			50%			30%	
				Walls	50%	30%	10%	50%	30%	10%	30%	10%
				Room Index	Coefficients of Utilization							
Indirect  Glass — Plastic — Metal	79 ↑ ↓ 3 	1.2 x Ceiling Height	Good .70 Med. .60 Poor .50	J	.16	.13	.11	.12	.10	.08	.06	.05
				I	.20	.16	.15	.15	.13	.11	.08	.07
				H	.23	.20	.17	.17	.14	.13	.10	.08
				G	.26	.23	.20	.20	.17	.15	.11	.10
				F	.29	.26	.22	.22	.19	.17	.12	.11
				E	.32	.29	.26	.24	.21	.19	.13	.12
				D	.36	.32	.30	.26	.24	.22	.15	.14
				C	.38	.35	.32	.28	.25	.24	.16	.15
				B	.42	.39	.36	.30	.29	.27	.18	.17
				A	.44	.41	.39	.33	.30	.29	.19	.18
Indirect  Silvered Bowl	85 ↑ ↓ 0 	1.2 x Ceiling Height	Good .65 Med. .60 Poor .55	J	.17	.14	.12	.13	.11	.09	.07	.06
				I	.21	.17	.16	.16	.14	.12	.09	.08
				H	.24	.21	.18	.18	.15	.14	.11	.09
				G	.27	.24	.21	.21	.18	.16	.12	.11
				F	.30	.27	.23	.23	.20	.18	.13	.12
				E	.33	.30	.27	.25	.22	.20	.14	.13
				D	.37	.33	.31	.27	.25	.23	.16	.15
				C	.39	.36	.33	.29	.26	.25	.17	.16
				B	.43	.40	.37	.31	.30	.28	.19	.18
				A	.45	.42	.40	.34	.31	.30	.20	.19
Indirect  Metal — Glass — Plastic	80 ↑ ↓ 0 	1.2 x Ceiling Height	Good .60 Med. .50 Poor .40	J	.15	.11	.10	.09	.08	.06	.04	.03
				I	.19	.15	.13	.12	.10	.09	.06	.04
				H	.22	.19	.16	.14	.12	.10	.07	.05
				G	.26	.22	.19	.17	.14	.13	.08	.07
				F	.28	.24	.21	.19	.16	.14	.09	.08
				E	.32	.28	.25	.21	.18	.17	.11	.10
				D	.35	.31	.29	.23	.21	.19	.12	.11
				C	.38	.34	.31	.25	.22	.21	.13	.12
				B	.42	.39	.36	.27	.25	.24	.15	.14
				A	.43	.41	.38	.29	.27	.25	.16	.15

PRECALCULATED FOOTCANDLE TABLE

Footcandles for Each 1000 Lamp Lumens (See Note on Page 6—5)

* Area (Square Feet)	Maintenance Factor	Coefficient of Utilization																									
		.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
2	70	70.0	77.0	84.0	91.0	98.0	105.	112.	119.	126.	133.	140.	147.	154.	161.	168.	175.	182.	189.	196.	203.	210.	217.	224.	231.	238.	245.
	60	60.0	66.0	72.0	78.0	84.0	90.0	96.0	102.	108.	114.	120.	126.	132.	138.	144.	150.	156.	162.	168.	174.	180.	186.	192.	198.	204.	210.
	50	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.	105.	110.	115.	120.	125.	130.	135.	140.	145.	150.	155.	160.	165.	170.	175.
	40	40.0	44.0	48.0	52.0	56.0	60.0	64.0	68.0	72.0	76.0	80.0	84.0	88.0	92.0	96.0	100.	104.	108.	112.	116.	120.	124.	128.	132.	136.	140.
3	70	46.6	51.3	56.0	60.6	65.3	70.0	74.6	79.3	84.0	88.6	93.3	98.0	103.	107.	112.	117.	121.	126.	131.	135.	140.	145.	149.	154.	159.	163.
	60	40.0	44.0	48.0	52.0	56.0	60.0	64.0	68.0	72.0	76.0	80.0	84.0	88.0	92.0	96.0	100.	104.	108.	112.	116.	120.	124.	128.	132.	136.	140.
	50	33.3	36.6	40.0	43.3	46.6	50.0	53.3	56.6	60.0	63.3	66.6	70.0	73.3	76.6	80.0	83.3	86.6	90.0	93.3	96.6	100.	103.	107.	110.	113.	117.
	40	26.6	29.3	32.0	34.6	37.3	40.0	42.6	45.3	48.0	50.6	53.3	56.0	58.6	61.3	64.0	66.6	69.3	72.0	74.6	77.3	80.0	82.6	85.3	88.0	90.6	93.3
4	70	35.0	38.5	42.0	45.5	49.0	52.5	56.0	59.5	63.0	66.5	70.0	73.5	77.0	80.5	84.0	87.5	91.0	94.5	98.0	102.	105.	109.	112.	116.	119.	123.
	60	30.0	33.0	36.0	39.0	42.0	45.0	48.0	51.0	54.0	57.0	60.0	63.0	66.0	69.0	72.0	75.0	78.0	81.0	84.0	87.0	90.0	93.0	96.0	99.0	102.	105.
	50	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5	70.0	72.5	75.0	77.5	80.0	82.5	85.0	87.5
	40	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0
5	70	28.0	31.0	33.6	36.4	39.2	42.0	44.7	47.6	50.2	53.2	56.0	58.8	61.6	64.4	67.2	70.0	72.8	75.6	78.4	81.2	84.0	86.8	89.6	92.4	95.2	98.0
	60	24.0	26.4	28.8	31.2	33.6	36.0	38.4	40.8	43.2	45.6	48.0	50.4	52.8	55.2	57.6	60.0	62.4	64.8	67.2	69.6	72.0	74.4	76.8	79.2	81.6	84.0
	50	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0
	40	16.0	17.6	19.2	20.8	22.4	24.0	25.6	27.2	28.8	30.4	32.0	33.6	35.2	36.8	38.4	40.0	41.6	43.2	44.8	46.4	48.0	49.6	51.2	52.8	54.4	56.0
6	70	23.3	25.6	28.0	30.3	32.7	35.0	37.1	39.7	42.0	44.3	46.6	49.0	51.3	53.6	56.0	58.3	60.6	63.0	65.3	67.6	70.0	72.3	74.6	77.0	79.3	81.6
	60	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0
	50	16.6	18.3	20.0	21.6	23.3	25.0	26.6	28.3	30.0	31.6	33.3	35.0	36.6	38.3	40.0	41.6	43.3	45.0	46.6	48.3	50.0	51.6	53.3	55.0	56.6	58.3
	40	13.3	14.6	16.0	17.3	18.6	20.0	21.3	22.6	24.0	25.3	26.6	28.0	29.3	30.6	32.0	33.3	34.6	36.0	37.3	38.6	40.0	41.3	42.6	44.0	45.3	46.6
7	70	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0
	60	17.1	18.8	20.5	22.2	23.9	25.7	27.4	29.1	30.8	32.5	34.2	35.9	37.7	39.4	41.1	42.8	44.5	46.2	47.9	49.7	51.4	53.1	54.8	56.5	58.2	59.9
	50	14.3	15.7	17.1	18.5	20.0	21.4	22.8	24.3	25.7	27.1	28.5	30.0	31.4	32.8	34.3	35.7	37.1	38.5	40.0	41.4	42.8	44.3	45.7	47.1	48.5	50.0
	40	11.4	12.5	13.7	14.8	16.0	17.1	18.2	19.4	20.5	21.7	22.8	24.0	25.1	26.2	27.4	28.5	29.7	30.8	32.0	33.1	34.2	35.4	36.5	37.7	38.8	40.0
8	70	17.5	19.2	21.0	22.7	24.5	26.2	28.0	29.7	31.5	33.4	35.0	36.7	38.5	40.2	42.0	43.7	45.5	47.2	49.0	50.7	52.5	54.2	56.0	57.7	59.5	61.2
	60	15.0	16.5	18.0	19.5	21.0	22.5	24.0	25.5	27.0	28.5	30.0	31.5	33.0	34.5	36.0	37.5	39.0	40.5	42.0	43.5	45.0	46.5	48.0	49.5	51.0	52.5
	50	12.5	13.7	15.0	16.2	17.5	18.7	20.0	21.2	22.5	23.7	25.0	26.2	27.5	28.7	30.0	31.2	32.5	33.7	35.0	36.2	37.5	38.7	40.0	41.2	42.5	43.7
	40	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
9	70	15.5	17.1	18.6	20.2	21.8	23.3	24.5	26.4	28.0	29.5	31.2	32.6	34.2	35.7	37.3	38.8	40.4	42.0	43.5	45.1	46.6	48.2	49.7	51.3	52.8	54.4
	60	13.3	14.6	16.0	17.3	18.6	20.0	21.3	22.6	24.0	25.3	26.6	28.0	29.3	30.6	32.0	33.3	34.6	36.0	37.3	38.6	40.0	41.3	42.6	44.0	45.3	46.6
	50	11.1	12.2	13.3	14.4	15.5	16.6	17.7	18.8	20.0	21.1	22.2	23.3	24.4	25.5	26.6	27.7	28.8	30.0	31.1	32.2	33.3	34.4	35.5	36.6	37.7	38.8
	40	8.88	9.77	10.6	11.5	12.4	13.3	14.2	15.1	16.0	16.8	17.7	18.6	19.5	20.4	21.3	22.2	23.1	24.0	24.8	25.7	26.6	27.5	28.4	29.3	30.2	31.1

* Area may represent floor area in square feet per lamp, luminaire, or room.

PRECALCULATED FOOTCANDLE TABLE
Footcandles for Each 1000 Lamp Lumens (See Note on Page 6—5)

*Area (Square Feet)	Maintenance Factor	Coefficient of Utilization																									
		.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
10	70	14.0	15.4	16.8	18.2	19.6	21.0	22.4	23.8	25.2	26.6	28.0	29.4	30.8	32.2	33.6	35.0	36.4	37.8	39.2	40.6	42.0	43.4	44.8	46.2	47.6	49.0
	60	12.0	13.2	14.4	15.6	16.8	18.0	19.2	20.4	21.6	22.8	24.0	25.2	26.4	27.6	28.8	30.0	31.2	32.4	33.6	34.8	36.0	37.2	38.4	39.6	40.8	42.0
	50	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
	40	8.00	8.80	9.60	10.4	11.2	12.0	12.8	13.6	14.4	15.2	16.0	16.8	17.6	18.4	19.2	20.0	20.8	21.6	22.4	23.2	24.0	24.8	25.6	26.4	27.2	28.0
12	70	11.6	12.8	14.0	15.1	16.3	17.5	18.5	19.5	21.0	22.1	23.3	24.5	25.6	26.8	28.0	29.1	30.3	31.5	32.6	33.8	35.0	36.1	37.3	38.5	39.6	40.8
	60	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
	50	8.33	9.17	10.0	10.8	11.6	12.5	13.3	14.2	15.0	15.8	16.6	17.5	18.3	19.2	20.0	20.8	21.6	22.5	23.3	24.1	25.0	25.8	26.6	27.5	28.3	29.1
	40	6.66	7.33	8.00	8.66	9.33	10.0	10.6	11.3	12.0	12.6	13.3	14.0	14.6	15.3	16.0	16.6	17.3	18.0	18.6	19.3	20.0	20.6	21.3	22.0	22.6	23.3
14	70	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0
	60	8.57	9.42	10.2	11.1	12.0	12.8	13.7	14.5	15.4	16.2	17.1	18.0	18.8	19.7	20.5	21.4	22.2	23.1	24.0	24.8	25.7	26.5	27.4	28.2	29.1	30.0
	50	7.14	7.85	8.57	9.28	9.99	10.7	11.4	12.1	12.8	13.5	14.2	15.0	15.7	16.4	17.1	17.8	18.5	19.2	20.0	20.7	21.4	22.1	22.8	23.5	24.2	25.0
	40	5.71	6.28	6.85	7.42	8.00	8.57	9.14	9.71	10.2	10.8	11.4	12.0	12.5	13.1	13.7	14.2	14.8	15.4	16.0	16.5	17.1	17.7	18.2	18.8	19.4	20.0
16	70	8.75	9.60	10.5	11.3	12.2	13.1	14.0	14.8	15.7	16.6	17.5	18.3	19.2	20.1	21.0	21.8	22.7	23.6	24.5	25.3	26.2	27.1	28.0	28.8	29.7	30.6
	60	7.50	8.25	9.00	9.75	10.5	11.2	12.0	12.7	13.5	14.2	15.0	15.7	16.5	17.2	18.0	18.7	19.5	20.2	21.0	21.7	22.5	23.2	24.0	24.7	25.5	26.2
	50	6.25	6.87	7.50	8.12	8.75	9.37	10.0	10.6	11.2	11.8	12.5	13.1	13.7	14.3	15.0	15.6	16.2	16.8	17.5	18.1	18.7	19.3	20.0	20.6	21.2	21.8
	40	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
18	70	7.80	8.55	9.35	10.1	10.9	11.6	12.4	13.2	14.0	14.7	15.5	16.3	17.1	17.8	18.6	19.4	20.2	21.0	21.7	22.5	23.3	24.1	24.8	25.6	26.4	27.2
	60	6.66	7.33	8.00	8.66	9.33	10.0	10.6	11.3	12.0	12.6	13.3	14.0	14.6	15.3	16.0	16.6	17.3	18.0	18.6	19.3	20.0	20.6	21.3	22.0	22.6	23.3
	50	5.55	6.11	6.67	7.22	7.77	8.33	8.88	9.44	10.0	10.5	11.1	11.6	12.2	12.7	13.3	13.8	14.4	15.0	15.5	16.1	16.6	17.2	17.7	18.3	18.8	19.4
	40	4.44	4.88	5.33	5.77	6.22	6.66	7.11	7.55	8.00	8.44	8.88	9.33	9.77	10.2	10.6	11.1	11.5	12.0	12.4	12.8	13.3	13.7	14.2	14.6	15.1	15.5
20	70	7.00	7.70	8.40	9.10	9.80	10.5	11.2	11.9	12.6	13.3	14.0	14.7	15.4	16.1	16.8	17.5	18.2	18.9	19.6	20.3	21.0	21.7	22.4	23.1	23.8	24.5
	60	6.00	6.60	7.20	7.80	8.40	9.00	9.60	10.2	10.8	11.4	12.0	12.6	13.2	13.8	14.4	15.0	15.6	16.2	16.8	17.4	18.0	18.6	19.2	19.8	20.4	21.0
	50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
	40	4.00	4.40	4.80	5.20	5.60	6.00	6.40	6.80	7.20	7.60	8.00	8.40	8.80	9.20	9.60	10.0	10.4	10.8	11.2	11.6	12.0	12.4	12.8	13.2	13.6	14.0
22	70	6.36	7.00	7.65	8.27	8.90	9.55	10.0	10.8	11.4	12.1	12.7	13.3	14.0	14.6	15.2	15.9	16.5	17.1	17.8	18.4	19.0	19.7	20.3	21.0	21.6	22.3
	60	5.45	6.00	6.54	7.09	7.63	8.18	8.72	9.27	9.81	10.3	10.9	11.4	12.0	12.5	13.0	13.6	14.1	14.7	15.2	15.8	16.3	16.9	17.4	18.0	18.5	19.0
	50	4.54	5.00	5.45	5.90	6.36	6.81	7.27	7.72	8.18	8.63	9.09	9.54	10.0	10.4	10.9	11.3	11.8	12.2	12.7	13.1	13.6	14.0	14.5	15.0	15.4	15.9
	40	3.63	4.00	4.36	4.72	5.09	5.45	5.81	6.18	6.54	6.90	7.27	7.63	8.00	8.36	8.72	9.09	9.45	9.82	10.2	10.5	10.9	11.2	11.6	12.0	12.3	12.7
24	70	5.75	6.40	7.00	7.60	8.00	8.75	9.34	9.92	10.5	11.0	11.6	12.2	12.8	13.4	14.0	14.5	15.1	15.7	16.3	16.9	17.5	18.0	18.6	19.2	19.8	20.4
	60	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
	50	4.16	4.58	5.00	5.41	5.83	6.25	6.66	7.08	7.50	7.91	8.33	8.75	9.16	9.58	10.0	10.4	10.8	11.2	11.6	12.0	12.5	12.9	13.3	13.7	14.1	14.5
	40	3.33	3.66	4.00	4.33	4.66	5.00	5.33	5.66	6.00	6.33	6.66	7.00	7.33	7.66	8.00	8.33	8.66	9.00	9.33	9.66	10.0	10.3	10.6	11.0	11.3	11.6

PRECALCULATED FOOTCANDLE TABLE

26	70	5.38	5.92	6.46	7.00	7.55	8.07	8.62	9.16	9.67	10.2	10.7	11.3	11.8	12.3	12.9	13.4	14.0	14.5	15.0	15.6	16.1	16.6	17.2	17.7	18.3	18.8
	60	4.61	5.07	5.53	6.00	6.46	6.92	7.38	7.84	8.30	8.77	9.23	9.69	10.1	10.6	11.0	11.5	12.0	12.4	12.9	13.3	13.8	14.3	14.7	15.2	15.7	16.1
	50	3.84	4.23	4.61	5.00	5,38	5.76	6.15	6.53	6.92	7.30	7.69	8.07	8.46	8.84	9.23	9.61	10.0	10.3	10.7	11.1	11.5	11.9	12.3	12.7	13.0	13.4
	40	3.07	3.38	3.69	4.00	4.30	4.61	4.92	5.23	5.54	5.84	6.15	6.46	6.76	7.07	7.38	7.69	8.00	8.30	8.61	8.92	9.23	9.54	9.84	10.1	10.4	10.7
28	70	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
	60	4.28	4.71	5.14	5.57	6.00	6.43	6.85	7.28	7.71	8.14	8.57	9.00	9.43	9.85	10.3	10.7	11.1	11.5	12.0	12.4	12.8	13.3	13.7	14.1	14.5	15.0
	50	3.57	3.93	4.28	4.64	5.00	5.35	5.71	6.07	6.42	6.78	7.14	7.50	7.85	8.21	8.57	8.92	9.28	9.64	10.0	10.3	10.7	11.0	11.4	11.8	12.1	12.5
	40	2.85	3.14	3.42	3.71	4.00	4.28	4.57	4.85	5.14	5.42	5.71	6.00	6.28	6.57	6.85	7.14	7.42	7.71	8.00	8.28	8.57	8.85	9.14	9.42	9.71	10.0
30	70	4.68	5.13	5.60	6.07	6.54	7.00	7.47	7.94	8.40	8.86	9.32	9.80	10.0	10.7	11.2	11.6	12.1	12.6	13.0	13.5	14.0	14.4	14.9	15.4	15.8	16.3
	60	4.00	4.40	4.80	5.20	5.60	6.00	6.40	6.80	7.20	7.60	8.00	8.40	8.80	9.20	9.60	10.0	10.4	10.8	11.2	11.6	12.0	12.4	12.8	13.2	13.6	14.0
	50	3.33	3.66	4.00	4.33	4.66	5.00	5.33	5.66	6.00	6.33	6.66	7.00	7.33	7.66	8.00	8.33	8.66	9.00	9.33	9.66	10.0	10.3	10.6	11.0	11.3	11.6
	40	2.66	2.93	3.20	3.46	3.73	4.00	4.26	4.53	4.80	5.06	5.33	5.60	5.86	6.13	6.40	6.66	6.93	7.20	7.46	7.73	8.00	8.26	8.53	8.80	9.06	9.33
35	70	4.00	4.40	4.80	5.20	5.60	6.00	6.40	6.80	7.20	7.60	8.00	8.40	8.80	9.20	9.60	10.0	10.4	10.8	11.2	11.6	12.0	12.4	12.8	13.2	13.6	14.0
	60	3.42	3.77	4.11	4.45	4.80	5.14	5.48	5.83	6.17	6.51	6.85	7.20	7.54	7.88	8.23	8.57	8.91	9.25	9.60	9.94	10.3	10.6	10.9	11.3	11.6	12.0
	50	2.85	3.14	3.43	3.71	4.00	4.28	4.57	4.85	5.14	5.43	5.71	6.00	6.28	6.57	6.85	7.14	7.42	7.71	8.00	8.28	8.57	8.85	9.14	9.43	9.71	10.0
	40	2.28	2.51	2.74	2.97	3.20	3.42	3.65	3.88	4.11	4.34	4.57	4.80	5.02	5.25	5.48	5.71	5.94	6.17	6.40	6.62	6.85	7.08	7.31	7.54	7.77	8.00
40	70	3.50	3.85	4.20	4.55	4.90	5.25	5.60	5.95	6.30	6.65	7.00	7.30	7.70	8.05	8.40	8.75	9.10	9.45	9.80	10.1	10.5	10.8	11.2	11.5	11.9	12.2
	60	3.00	3.30	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00	6.30	6.60	6.90	7.20	7.50	7.80	8.10	8.40	8.70	9.00	9.30	9.60	9.90	10.2	10.5
	50	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75
	40	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
45	70	3.11	3.42	3.72	4.04	4.35	4.65	4.95	5.29	5.60	5.90	6.22	6.40	6.84	7.15	7.46	7.77	8.08	8.40	8.71	9.02	9.33	9.64	9.95	10.2	10.5	10.9
	60	2.66	2.93	3.20	3.46	3.73	4.00	4.26	4.53	4.80	5.06	5.33	5.60	5.86	6.13	6.40	6.66	6.93	7.20	7.46	7.73	8.00	8.26	8.53	8.80	9.06	9.33
	50	2.22	2.44	2.66	2.88	3.11	3.33	3.55	3.77	4.00	4.22	4.44	4.66	4.88	5.11	5.33	5.55	5.77	6.00	6.22	6.44	6.66	6.88	7.11	7.33	7.55	7.77
	40	1.77	1.95	2.13	2.31	2.48	2.66	2.84	3.02	3.20	3.37	3.55	3.73	3.91	4.08	4.26	4.44	4.62	4.80	4.97	5.15	5.33	5.51	5.68	5.86	6.04	6.22
50	70	2.80	3.08	3.36	3.64	3.92	4.20	4.47	4.76	5.02	5.32	5.60	5.88	6.16	6.44	6.72	7.00	7.28	7.56	7.84	8.12	8.40	8.68	8.96	9.24	9.52	9.80
	60	2.40	2.64	2.88	3.12	3.36	3.60	3.84	4.08	4.32	4.56	4.80	5.04	5.28	5.52	5.76	6.00	6.24	6.48	6.72	6.96	7.20	7.44	7.68	7.92	8.16	8.40
	50	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
	40	1.60	1.76	1.92	2.08	2.24	2.40	2.56	2.72	2.88	3.04	3.20	3.36	3.52	3.68	3.84	4.00	4.16	4.32	4.48	4.64	4.80	4.96	5.12	5.28	5.44	5.60
55	70	2.54	2.80	3.06	3.30	3.56	3.82	4.07	4.33	4.58	4.83	5.09	5.30	5.60	5.85	6.10	6.36	6.61	6.87	7.12	7.38	7.63	7.89	8.14	8.40	8.65	8.90
	60	2.18	2.40	2.62	2.83	3.05	3.27	3.49	3.71	3.92	4.14	4.36	4.58	4.80	5.02	5.23	5.45	5.67	5.89	6.11	6.32	6.54	6.76	6.98	7.20	7.42	7.63
	50	1.82	2.00	2.18	2.36	2.54	2.72	2.90	3.09	3.27	3.45	3.63	3.82	4.00	4.18	4.36	4.54	4.72	4.90	5.09	5.27	5.45	5.63	5.82	6.00	6.18	6.36
	40	1.45	1.60	1.74	1.89	2.03	2.18	2.32	2.47	2.61	2.76	2.90	3.05	3.20	3.34	3.49	3.63	3.78	3.92	4.07	4.21	4.36	4.50	4.65	4.80	4.94	5.09
60	70	2.33	2.57	2.80	3.03	3.27	3.50	3.71	3.97	4.20	4.43	4.66	4.90	5.13	5.36	5.60	5.83	6.96	6.30	6.53	6.76	7.00	7.23	7.46	7.70	7.93	8.16
	60	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
	50	1.66	1.83	2.00	2.16	2.33	2.50	2.66	2.83	3.00	3.16	3.33	3.50	3.66	3.83	4.00	4.16	4.33	4.50	4.66	4.83	5.00	5.16	5.33	5.50	5.66	5.83
	40	1.33	1.46	1.60	1.73	1.86	2.00	2.13	2.26	2.40	2.53	2.66	2.80	2.93	3.06	3.20	3.33	3.46	3.60	3.73	3.86	4.00	4.13	4.26	4.40	4.53	4.66

* Area may represent floor area in square feet per lamp, luminaire, or room.

PRECALCULATED FOOTCANDLE TABLE

Footcandles for Each 1000 Lamp Lumens (See Note on Page 6—5)

*Area (Square Feet)	Maintenance Factor	Coefficient of Utilization																									
		.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
70	70	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00	6.20	6.40	6.60	6.80	7.00
	60	1.71	1.88	2.05	2.23	2.40	2.57	2.74	2.91	3.08	3.25	3.43	3.60	3.77	3.94	4.11	4.28	4.45	4.63	4.80	4.97	5.14	5.31	5.48	5.66	5.83	6.00
	50	1.43	1.57	1.71	1.85	2.00	2.14	2.28	2.43	2.57	2.71	2.85	3.00	3.14	3.28	3.43	3.57	3.71	3.85	4.00	4.14	4.28	4.43	4.57	4.71	4.85	5.00
	40	1.14	1.25	1.37	1.48	1.60	1.71	1.82	1.94	2.05	2.17	2.28	2.40	2.51	2.62	2.74	2.85	2.97	3.08	3.20	3.31	3.42	3.54	3.65	3.77	3.88	4.00
80	70	1.75	1.92	2.10	2.27	2.45	2.62	2.80	2.97	3.15	3.34	3.50	3.67	3.85	4.02	4.20	4.37	4.55	4.72	4.90	5.07	5.25	5.42	5.60	5.77	5.95	6.12
	60	1.50	1.65	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85	3.00	3.15	3.30	3.45	3.60	3.75	3.90	4.05	4.20	4.35	4.50	4.65	4.80	4.95	5.10	5.25
	50	1.25	1.37	1.50	1.62	1.75	1.87	2.00	2.12	2.25	2.37	2.50	2.62	2.75	2.87	3.00	3.12	3.25	3.37	3.50	3.62	3.75	3.87	4.00	4.12	4.25	4.37
	40	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50
90	70	1.55	1.71	1.86	2.02	2.18	2.33	2.45	2.64	2.80	2.95	3.12	3.26	3.42	3.57	3.73	3.88	4.04	4.20	4.35	4.51	4.66	4.82	4.97	5.13	5.28	5.44
	60	1.33	1.46	1.60	1.73	1.86	2.00	2.13	2.26	2.40	2.53	2.66	2.80	2.93	3.06	3.20	3.33	3.46	3.60	3.73	3.86	4.00	4.13	4.26	4.40	4.53	4.66
	50	1.11	1.22	1.33	1.44	1.55	1.66	1.77	1.88	2.00	2.11	2.22	2.33	2.44	2.55	2.66	2.77	2.88	3.00	3.11	3.22	3.33	3.44	3.55	3.66	3.77	3.88
	40	.889	.977	1.06	1.15	1.24	1.33	1.42	1.51	1.60	1.68	1.77	1.86	1.95	2.04	2.13	2.22	2.31	2.40	2.48	2.57	2.66	2.75	2.84	2.93	3.02	3.11
100	70	1.40	1.54	1.68	1.82	1.96	2.10	2.24	2.38	2.52	2.66	2.80	2.94	3.08	3.22	3.36	3.50	3.64	3.78	3.92	4.06	4.20	4.34	4.48	4.62	4.76	4.90
	60	1.20	1.32	1.44	1.56	1.68	1.80	1.92	2.04	2.16	2.28	2.40	2.52	2.64	2.76	2.88	3.00	3.12	3.24	3.36	3.48	3.60	3.72	3.84	3.96	4.08	4.20
	50	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50
	40	.800	.880	.960	1.04	1.12	1.20	1.28	1.36	1.44	1.52	1.60	1.68	1.76	1.84	1.92	2.00	2.08	2.16	2.24	2.32	2.40	2.48	2.56	2.64	2.72	2.80
110	70	1.27	1.40	1.53	1.65	1.78	1.91	2.04	2.16	2.29	2.42	2.55	2.67	2.80	2.93	3.05	3.18	3.31	3.44	3.56	3.69	3.82	3.96	4.07	4.20	4.33	4.45
	60	1.09	1.20	1.31	1.42	1.53	1.64	1.76	1.85	1.96	2.07	2.18	2.29	2.40	2.51	2.62	2.73	2.84	2.96	3.05	3.16	3.27	3.38	3.49	3.60	3.71	3.82
	50	.909	.999	1.09	1.18	1.27	1.36	1.45	1.54	1.64	1.73	1.82	1.91	2.00	2.09	2.18	2.27	2.36	2.45	2.55	2.64	2.73	2.82	2.91	3.00	3.09	3.18
	40	.727	.800	.873	.945	1.02	1.09	1.16	1.24	1.31	1.38	1.45	1.53	1.60	1.67	1.75	1.82	1.89	1.96	2.04	2.11	2.18	2.25	2.33	2.40	2.47	2.55
120	70	1.16	1.28	1.40	1.51	1.63	1.75	1.85	1.95	2.10	2.21	2.33	2.45	2.56	2.68	2.80	2.91	3.03	3.15	3.26	3.38	3.50	3.61	3.73	3.85	3.96	4.08
	60	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50
	50	.833	.917	1.00	1.08	1.16	1.25	1.33	1.42	1.50	1.58	1.66	1.75	1.83	1.92	2.00	2.08	2.16	2.25	2.33	2.41	2.50	2.58	2.66	2.75	2.83	2.91
	40	.666	.733	.800	.866	.933	1.00	1.06	1.13	1.20	1.26	1.33	1.40	1.46	1.53	1.60	1.66	1.73	1.80	1.86	1.93	2.00	2.06	2.13	2.20	2.26	2.33
130	70	1.08	1.18	1.29	1.40	1.51	1.62	1.72	1.83	1.94	2.05	2.15	2.26	2.37	2.48	2.58	2.69	2.80	2.91	3.02	3.12	3.23	3.34	3.45	3.55	3.66	3.77
	60	.923	1.02	1.11	1.20	1.29	1.38	1.48	1.57	1.66	1.75	1.85	1.94	2.03	2.12	2.22	2.31	2.40	2.49	2.58	2.68	2.77	2.86	2.95	3.05	3.14	3.23
	50	.769	.846	.923	1.00	1.08	1.15	1.23	1.31	1.38	1.46	1.54	1.62	1.69	1.77	1.85	1.92	2.00	2.08	2.15	2.23	2.31	2.38	2.46	2.54	2.62	2.69
	40	.615	.677	.738	.800	.862	.923	.985	1.05	1.11	1.17	1.23	1.29	1.35	1.42	1.48	1.54	1.60	1.66	1.72	1.78	1.85	1.91	1.97	2.03	2.09	2.15
140	70	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	3.40	3.50
	60	.857	.942	1.02	1.11	1.20	1.28	1.37	1.45	1.54	1.62	1.71	1.80	1.88	1.97	2.05	2.14	2.22	2.31	2.40	2.48	2.57	2.65	2.74	2.82	2.91	3.00
	50	.714	.785	.857	.928	.999	1.07	1.14	1.21	1.28	1.35	1.42	1.50	1.57	1.64	1.71	1.78	1.85	1.92	2.00	2.07	2.14	2.21	2.28	2.35	2.42	2.50
	40	.571	.628	.685	.742	.800	.857	.914	.971	1.02	1.08	1.14	1.20	1.25	1.31	1.37	1.42	1.48	1.54	1.60	1.65	1.71	1.77	1.82	1.88	1.94	2.00

PRECALCULATED FOOTCANDLE TABLE

150	70	.932	1.02	1.12	1.21	1.31	1.40	1.49	1.58	1.68	1.77	1.86	1.96	2.05	2.14	2.24	2.33	2.42	2.52	2.61	2.70	2.80	2.89	2.98	3.08	3.17	3.26
	60	.800	.880	.960	1.04	1.12	1.20	1.28	1.36	1.44	1.52	1.60	1.68	1.76	1.84	1.90	1.98	2.06	2.14	2.22	2.30	2.38	2.46	2.54	2.62	2.70	2.78
	50	.666	.733	.800	.866	.933	1.00	1.06	1.13	1.20	1.26	1.33	1.40	1.46	1.53	1.60	1.66	1.73	1.80	1.86	1.93	2.00	2.06	2.13	2.20	2.26	2.33
	40	.533	.587	.640	.693	.747	.800	.853	.907	.960	1.01	1.06	1.12	1.17	1.22	1.28	1.33	1.38	1.44	1.49	1.54	1.60	1.65	1.70	1.76	1.81	1.86
160	70	.875	.960	1.05	1.13	1.22	1.31	1.40	1.48	1.57	1.66	1.75	1.83	1.92	2.01	2.10	2.18	2.27	2.36	2.45	2.53	2.62	2.71	2.80	2.88	2.97	3.06
	60	.750	.825	.900	.975	1.05	1.12	1.20	1.27	1.35	1.42	1.50	1.57	1.65	1.72	1.80	1.87	1.95	2.02	2.10	2.17	2.25	2.32	2.40	2.47	2.55	2.62
	50	.625	.687	.750	.812	.875	.937	1.00	1.06	1.12	1.18	1.25	1.31	1.37	1.43	1.50	1.56	1.62	1.68	1.75	1.81	1.87	1.93	2.00	2.06	2.12	2.18
	40	.500	.550	.600	.650	.700	.750	.800	.850	.900	.950	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
180	70	.780	.855	.935	1.01	1.09	1.16	1.24	1.32	1.40	1.47	1.55	1.63	1.71	1.78	1.86	1.94	2.02	2.10	2.17	2.25	2.33	2.41	2.48	2.56	2.64	2.72
	60	.666	.733	.800	.866	.933	1.00	1.06	1.13	1.20	1.26	1.33	1.40	1.46	1.53	1.60	1.66	1.73	1.80	1.86	1.93	2.00	2.06	2.13	2.20	2.26	2.33
	50	.555	.611	.667	.722	.777	.833	.888	.944	1.00	1.05	1.11	1.16	1.22	1.27	1.33	1.38	1.44	1.50	1.55	1.61	1.66	1.72	1.77	1.83	1.88	1.94
	40	.444	.488	.533	.577	.622	.666	.711	.755	.800	.844	.888	.933	.977	1.02	1.06	1.11	1.15	1.20	1.24	1.28	1.33	1.37	1.42	1.46	1.51	1.55
200	70	.700	.770	.840	.910	.980	1.05	1.12	1.19	1.26	1.33	1.40	1.47	1.54	1.61	1.68	1.75	1.82	1.89	1.96	2.03	2.10	2.17	2.24	2.31	2.38	2.45
	60	.600	.660	.720	.780	.840	.900	.960	1.02	1.08	1.14	1.20	1.26	1.32	1.38	1.44	1.50	1.56	1.62	1.68	1.74	1.80	1.86	1.92	1.98	2.04	2.10
	50	.500	.550	.600	.650	.700	.750	.800	.850	.900	.950	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
	40	.400	.440	.480	.520	.560	.600	.640	.680	.720	.760	.800	.840	.880	.920	.960	1.00	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40
220	70	.636	.700	.765	.827	.890	.955	1.00	1.08	1.14	1.21	1.27	1.33	1.40	1.46	1.52	1.59	1.65	1.71	1.78	1.84	1.90	1.97	2.03	2.10	2.16	2.23
	60	.545	.600	.654	.709	.763	.818	.872	.927	.981	1.03	1.09	1.14	1.20	1.25	1.30	1.36	1.41	1.47	1.52	1.58	1.63	1.69	1.74	1.80	1.85	1.90
	50	.454	.500	.545	.590	.636	.681	.727	.772	.818	.863	.909	.954	1.00	1.04	1.09	1.13	1.18	1.22	1.27	1.31	1.36	1.40	1.45	1.50	1.54	1.59
	40	.363	.400	.436	.472	.509	.545	.581	.618	.654	.690	.727	.763	.800	.836	.872	.909	.945	.982	1.02	1.05	1.09	1.12	1.16	1.20	1.23	1.27
240	70	.575	.640	.700	.760	.800	.875	.934	.992	1.05	1.10	1.16	1.22	1.28	1.34	1.40	1.45	1.51	1.57	1.63	1.69	1.75	1.80	1.86	1.92	1.98	2.04
	60	.500	.550	.600	.650	.700	.750	.800	.850	.900	.950	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
	50	.416	.458	.500	.541	.583	.625	.666	.708	.750	.791	.833	.875	.916	.958	1.00	1.04	1.08	1.12	1.16	1.20	1.25	1.29	1.33	1.37	1.41	1.45
	40	.333	.366	.400	.433	.466	.500	.533	.566	.600	.633	.666	.700	.733	.766	.800	.833	.866	.900	.933	.966	1.00	1.03	1.06	1.10	1.13	1.16
260	70	.538	.592	.646	.700	.755	.807	.862	.916	.967	1.02	1.07	1.13	1.18	1.23	1.29	1.34	1.40	1.45	1.50	1.56	1.61	1.66	1.72	1.77	1.83	1.88
	60	.461	.507	.553	.600	.646	.692	.738	.784	.830	.877	.923	.969	1.01	1.06	1.10	1.15	1.20	1.24	1.29	1.33	1.38	1.43	1.47	1.52	1.57	1.61
	50	.384	.423	.461	.500	.538	.576	.615	.653	.692	.730	.769	.807	.846	.884	.923	.961	1.00	1.03	1.07	1.11	1.15	1.19	1.23	1.27	1.30	1.34
	40	.307	.338	.369	.400	.430	.461	.492	.523	.554	.584	.615	.646	.676	.707	.738	.769	.800	.830	.861	.892	.923	.954	.984	1.01	1.04	1.07
280	70	.500	.550	.600	.650	.700	.750	.800	.850	.900	.950	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75
	60	.428	.471	.514	.557	.600	.643	.685	.728	.771	.814	.857	.900	.943	.985	1.03	1.07	1.11	1.15	1.20	1.24	1.28	1.33	1.37	1.41	1.45	1.50
	50	.357	.393	.428	.464	.500	.535	.571	.607	.642	.678	.714	.750	.785	.821	.857	.892	.928	.964	1.00	1.03	1.07	1.10	1.14	1.18	1.21	1.25
	40	.285	.314	.342	.371	.400	.428	.457	.485	.514	.542	.571	.600	.628	.657	.685	.714	.742	.771	.800	.828	.857	.885	.914	.942	.971	1.00
300	70	.468	.513	.560	.607	.654	.700	.747	.794	.840	.886	.932	.980	1.00	1.07	1.12	1.16	1.21	1.26	1.30	1.35	1.40	1.44	1.49	1.54	1.58	1.63
	60	.400	.440	.480	.520	.560	.600	.640	.680	.720	.760	.800	.840	.880	.920	.960	1.00	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40
	50	.333	.366	.400	.433	.466	.500	.533	.566	.600	.633	.666	.700	.733	.766	.800	.833	.866	.900	.933	.966	1.00	1.03	1.06	1.10	1.13	1.16
	40	.266	.293	.320	.346	.373	.400	.426	.453	.480	.506	.533	.560	.586	.613	.640	.666	.693	.720	.746	.773	.800	.826	.853	.880	.906	.933

* Area may represent floor area in square feet per lamp, luminaire, or room.

PRECALCULATED FOOTCANDLE TABLE

Footcandles for Each 1000 Lamp Lumens (See Note on Page 6—5)

*Area (Square Feet)	Maintenance Factor	Coefficient of Utilization																									
		.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
320	70	.438	.481	.525	.569	.613	.656	.700	.744	.788	.831	.875	.919	.963	1.01	1.05	1.09	1.14	1.18	1.23	1.27	1.31	1.36	1.40	1.44	1.49	1.53
	60	.375	.413	.450	.486	.525	.563	.600	.638	.675	.713	.750	.788	.825	.863	.900	.938	.975	1.01	1.05	1.09	1.13	1.16	1.20	1.24	1.28	1.31
	50	.313	.344	.375	.406	.438	.469	.500	.531	.563	.594	.625	.656	.688	.719	.750	.781	.813	.844	.875	.906	.938	.969	1.00	1.03	1.06	1.09
	40	.250	.275	.300	.325	.350	.375	.400	.425	.450	.475	.500	.525	.550	.575	.600	.625	.650	.675	.700	.725	.750	.775	.800	.825	.850	.875
340	70	.412	.453	.494	.535	.576	.617	.658	.700	.741	.782	.824	.865	.906	.947	.988	1.03	1.07	1.11	1.15	1.19	1.24	1.28	1.32	1.36	1.40	1.44
	60	.353	.388	.424	.459	.494	.529	.565	.600	.635	.671	.706	.741	.776	.812	.847	.882	.918	.953	.988	1.02	1.06	1.09	1.13	1.16	1.20	1.24
	50	.294	.324	.353	.382	.412	.441	.471	.500	.529	.559	.588	.618	.647	.676	.706	.735	.764	.794	.824	.853	.882	.912	.941	.971	1.00	1.03
	40	.235	.259	.282	.306	.329	.353	.376	.400	.426	.447	.471	.494	.518	.541	.565	.588	.612	.635	.659	.682	.706	.729	.753	.776	.800	.824
360	70	.389	.428	.467	.506	.544	.583	.622	.661	.700	.739	.778	.817	.856	.894	.933	.972	1.01	1.05	1.09	1.13	1.17	1.21	1.24	1.28	1.32	1.36
	60	.333	.367	.400	.433	.467	.500	.533	.567	.600	.633	.667	.700	.733	.767	.800	.833	.866	.900	.933	.967	1.00	1.03	1.07	1.10	1.13	1.17
	50	.278	.306	.333	.361	.389	.417	.444	.472	.500	.528	.556	.583	.611	.639	.667	.694	.722	.750	.778	.806	.833	.861	.889	.917	.944	.972
	40	.222	.244	.267	.289	.311	.333	.356	.378	.400	.422	.444	.467	.489	.511	.533	.556	.578	.600	.622	.644	.667	.689	.711	.733	.756	.778
380	70	.368	.405	.442	.479	.516	.553	.589	.626	.663	.700	.737	.774	.811	.847	.884	.921	.958	.995	1.03	1.07	1.11	1.14	1.18	1.22	1.25	1.29
	60	.315	.347	.379	.411	.442	.474	.505	.537	.568	.600	.632	.663	.695	.726	.758	.789	.821	.853	.884	.916	.947	.979	1.01	1.04	1.07	1.10
	50	.263	.289	.316	.342	.368	.395	.421	.447	.474	.500	.526	.553	.579	.605	.632	.658	.684	.711	.737	.763	.789	.816	.842	.868	.895	.921
	40	.211	.232	.253	.274	.295	.316	.337	.358	.379	.400	.421	.442	.463	.484	.505	.526	.547	.568	.589	.611	.632	.653	.674	.695	.716	.737
400	70	.350	.385	.420	.455	.490	.525	.560	.595	.630	.665	.700	.730	.770	.805	.840	.875	.910	.945	.980	1.01	1.05	1.08	1.12	1.15	1.19	1.22
	60	.300	.330	.360	.390	.420	.450	.480	.510	.540	.570	.600	.630	.660	.690	.720	.750	.780	.810	.840	.870	.900	.930	.960	.990	1.02	1.05
	50	.250	.275	.300	.325	.350	.375	.400	.425	.450	.475	.500	.525	.550	.575	.600	.625	.650	.675	.700	.725	.750	.775	.800	.825	.850	.875
	40	.200	.220	.240	.260	.280	.300	.320	.340	.360	.380	.400	.420	.440	.460	.480	.500	.520	.540	.560	.580	.600	.620	.640	.660	.680	.700
450	70	.311	.342	.372	.404	.435	.465	.495	.529	.560	.590	.622	.640	.684	.715	.746	.777	.808	.840	.871	.902	.933	.964	.995	1.02	1.05	1.09
	60	.266	.293	.320	.346	.373	.400	.426	.453	.480	.506	.533	.560	.586	.613	.640	.666	.693	.720	.746	.773	.800	.826	.853	.880	.906	.933
	50	.222	.244	.266	.288	.311	.333	.355	.377	.400	.422	.444	.466	.488	.511	.533	.555	.577	.600	.622	.644	.666	.688	.711	.733	.755	.777
	40	.177	.195	.213	.231	.248	.266	.284	.302	.320	.337	.355	.373	.391	.408	.426	.444	.462	.480	.497	.515	.533	.551	.568	.586	.604	.622
500	70	.280	.308	.336	.364	.392	.420	.447	.476	.502	.532	.560	.588	.616	.644	.672	.700	.728	.756	.784	.812	.840	.868	.896	.924	.952	.980
	60	.240	.264	.288	.312	.336	.360	.384	.408	.432	.456	.480	.504	.528	.552	.576	.600	.624	.648	.672	.696	.720	.744	.768	.792	.816	.840
	50	.200	.220	.240	.260	.280	.300	.320	.340	.360	.380	.400	.420	.440	.460	.480	.500	.520	.540	.560	.580	.600	.620	.640	.660	.680	.700
	40	.160	.176	.192	.208	.224	.240	.256	.272	.288	.304	.320	.336	.352	.368	.384	.400	.416	.432	.448	.464	.480	.496	.512	.528	.544	.560
600	70	.233	.257	.280	.303	.327	.350	.371	.397	.420	.443	.466	.490	.513	.536	.560	.583	.606	.630	.653	.676	.700	.723	.746	.770	.793	.816
	60	.200	.220	.240	.260	.280	.300	.320	.340	.360	.380	.400	.420	.440	.460	.480	.500	.520	.540	.560	.580	.600	.620	.640	.660	.680	.700
	50	.166	.183	.200	.216	.233	.250	.266	.283	.300	.316	.333	.350	.366	.383	.400	.416	.433	.450	.466	.483	.500	.516	.533	.550	.566	.583
	40	.133	.146	.160	.173	.186	.200	.213	.226	.240	.253	.266	.280	.293	.306	.320	.333	.346	.360	.373	.386	.400	.413	.426	.440	.453	.466

PRECALCULATED FOOTCANDLE TABLE

700	70	.200	.220	.240	.260	.280	.300	.320	.340	.360	.380	.400	.420	.440	.460	.480	.500	.520	.540	.560	.580	.600	.620	.640	.660	.680	.700
	60	.171	.188	.205	.223	.240	.257	.274	.291	.308	.325	.343	.360	.377	.394	.411	.428	.445	.463	.480	.497	.514	.531	.548	.566	.583	.600
	50	.143	.157	.171	.185	.200	.214	.228	.243	.257	.271	.285	.300	.314	.328	.343	.357	.371	.385	.400	.414	.428	.443	.457	.471	.485	.500
	40	.114	.125	.137	.148	.160	.171	.182	.194	.205	.217	.228	.240	.251	.262	.274	.285	.297	.308	.320	.331	.342	.354	.365	.377	.388	.400
800	70	.175	.192	.210	.227	.245	.262	.280	.297	.315	.334	.350	.367	.385	.402	.420	.437	.455	.472	.490	.507	.525	.542	.560	.577	.595	.612
	60	.150	.165	.180	.195	.210	.225	.240	.255	.270	.285	.300	.315	.330	.345	.360	.375	.390	.405	.420	.435	.450	.465	.480	.495	.510	.525
	50	.125	.137	.150	.162	.175	.187	.200	.212	.225	.237	.250	.262	.275	.287	.300	.312	.325	.337	.350	.362	.375	.387	.400	.412	.425	.437
	40	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200	.210	.220	.230	.240	.250	.260	.270	.280	.290	.300	.310	.320	.330	.340	.350
900	70	.155	.171	.186	.202	.218	.233	.245	.264	.280	.295	.312	.326	.342	.357	.373	.388	.404	.420	.435	.451	.466	.482	.497	.513	.528	.544
	60	.133	.146	.160	.173	.186	.200	.213	.226	.240	.253	.266	.280	.293	.306	.320	.333	.346	.360	.373	.386	.400	.413	.426	.440	.453	.466
	50	.111	.122	.133	.144	.155	.166	.177	.188	.200	.211	.222	.233	.244	.255	.266	.277	.288	.300	.311	.322	.333	.344	.355	.366	.377	.388
	40	.090	.098	.106	.115	.124	.133	.142	.151	.160	.168	.177	.186	.195	.204	.213	.222	.231	.240	.248	.257	.266	.275	.284	.293	.302	.311
1000	70	.140	.154	.168	.182	.196	.210	.224	.238	.252	.266	.280	.294	.308	.322	.336	.350	.364	.378	.392	.406	.420	.434	.448	.462	.476	.490
	60	.120	.132	.144	.156	.168	.180	.192	.204	.216	.228	.240	.252	.264	.276	.288	.300	.312	.324	.336	.348	.360	.372	.384	.396	.408	.420
	50	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200	.210	.220	.230	.240	.250	.260	.270	.280	.290	.300	.310	.320	.330	.340	.350
	40	.080	.088	.096	.104	.112	.120	.128	.136	.144	.152	.160	.168	.176	.184	.192	.200	.208	.216	.224	.232	.240	.248	.256	.264	.272	.280
1200	70	.116	.128	.140	.151	.163	.175	.185	.195	.210	.221	.233	.245	.256	.268	.280	.291	.303	.315	.326	.338	.350	.361	.373	.385	.396	.408
	60	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200	.210	.220	.230	.240	.250	.260	.270	.280	.290	.300	.310	.320	.330	.340	.350
	50	.083	.092	.100	.108	.116	.125	.133	.142	.150	.158	.166	.175	.183	.192	.200	.208	.216	.225	.233	.241	.250	.258	.266	.275	.283	.291
	40	.067	.073	.080	.087	.093	.100	.106	.113	.120	.126	.133	.140	.146	.153	.160	.166	.173	.180	.186	.193	.200	.206	.213	.220	.226	.233
1400	70	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200	.210	.220	.230	.240	.250	.260	.270	.280	.290	.300	.310	.320	.330	.340	.350
	60	.086	.094	.102	.111	.120	.128	.137	.145	.154	.162	.171	.180	.188	.197	.205	.214	.222	.231	.240	.248	.257	.265	.274	.282	.291	.300
	50	.071	.079	.086	.093	.100	.107	.114	.121	.128	.135	.142	.150	.157	.164	.171	.178	.185	.192	.200	.207	.214	.221	.228	.235	.242	.250
	40	.057	.063	.069	.074	.080	.086	.091	.097	.102	.108	.114	.120	.125	.131	.137	.142	.148	.154	.160	.165	.171	.177	.182	.188	.194	.200
1600	70	.088	.096	.105	.113	.122	.131	.140	.148	.157	.166	.175	.183	.192	.201	.210	.218	.227	.236	.245	.253	.262	.271	.280	.288	.297	.306
	60	.075	.083	.090	.096	.105	.112	.120	.127	.135	.142	.150	.157	.165	.172	.180	.187	.195	.202	.210	.217	.225	.232	.240	.247	.255	.262
	50	.063	.069	.076	.081	.088	.094	.100	.106	.112	.118	.125	.131	.137	.143	.150	.156	.162	.168	.175	.181	.187	.193	.200	.206	.212	.218
	40	.050	.055	.060	.065	.070	.075	.080	.085	.090	.095	.100	.105	.110	.115	.120	.125	.130	.135	.140	.145	.150	.155	.160	.165	.170	.175
1800	70	.078	.086	.094	.101	.109	.116	.124	.132	.140	.147	.155	.163	.171	.178	.186	.194	.202	.210	.217	.225	.233	.241	.248	.256	.264	.272
	60	.067	.073	.080	.087	.093	.100	.106	.113	.120	.126	.133	.140	.146	.153	.160	.166	.173	.180	.186	.193	.200	.206	.213	.220	.226	.233
	50	.056	.061	.067	.072	.078	.083	.089	.094	.100	.105	.111	.116	.122	.127	.133	.138	.144	.150	.155	.161	.166	.172	.177	.183	.188	.194
	40	.044	.049	.053	.058	.062	.067	.071	.076	.080	.084	.089	.093	.098	.102	.106	.111	.115	.120	.124	.128	.133	.137	.142	.146	.151	.155
2000	70	.070	.077	.084	.091	.098	.105	.112	.119	.126	.133	.140	.147	.154	.161	.168	.175	.182	.189	.196	.203	.210	.217	.224	.231	.238	.245
	60	.060	.066	.072	.078	.084	.090	.096	.102	.108	.114	.120	.126	.132	.138	.144	.150	.156	.162	.168	.174	.180	.186	.192	.198	.204	.210
	50	.050	.055	.060	.065	.070	.075	.080	.085	.090	.095	.100	.105	.110	.115	.120	.125	.130	.135	.140	.145	.150	.155	.160	.165	.170	.175
	40	.040	.044	.048	.052	.056	.060	.064	.068	.072	.076	.080	.084	.088	.092	.096	.100	.104	.108	.112	.116	.120	.124	.128	.132	.136	.140

* Area may represent floor area in square feet per lamp, luminaire, or room.

LAMP DATA

Fluorescent

Watts	Bulb	Base	Color	Burning Hours Per Start	Rated Avg. Life (Hours)	Initial Lumens
Standard Lamps						
40	T-12	Med. Bipin	White†	3 6 12	2500 4000 6000	2320
40	T-12	Med. Bipin	Daylight	3 6 12	2500 4000 6000	1920
100	T-17	Mog. Bipin	White†	3 6 12	3000 4500 6500	4200
100	T-17	Mog. Bipin	Daylight	3 6 12	3000 4500 6500	3900
Slimline Lamps				**Amperes**		
16 25 33	42″T-6	Single-Pin	4500 White	0.1 0.2 0.3	2500* 2500* 2500*	880 1320 1620
24 39 51	64″T-6	Single-Pin	4500 White	0.1 0.2 0.3	2500* 2500* 2500*	1370 2150 2600
22 38 51	72″T-8	Single-Pin	4500 White	0.1 0.2 0.3	2500* 2500* 2500*	1340 2250 2850
29 51 69	96″T-8	Single-Pin	4500 White	0.1 0.2 0.3	2500* 2500* 2500*	1800 3050 3950

† The 4500 White lamp is about halfway between White and Daylight in both color and lumen output. The Soft White lamp produces about 25% less light than the White.

* Life under specified test conditions at 3 burning hours per start. At 6 hours per start it will be 4000 hours and at 12 hours per start 6000 hours.

Approximate Ballast Loss—Watts per Lamp

Lamp	110–125 Volt			220–250 Volt		
	Single-Lamp		Two-Lamp	Single-Lamp		Two-Lamp
	Low PF	High PF	High PF	Low PF	High PF	High PF
Fluorescent						
40-W 48″ T-12	13	15	8.75	12	13	7.25
40-W 48″ T-12 (Inst. Start)	.....	.....	14	.....	.....	12.5
100-W 60″ T-17	.....	24	17.5	.....	24	17.5
Slimline						
16-W 42″ T-6 (.1 Amp.)	11	10	5.75	.....	.....	.....
25-W 42″ T-6 (.2 Amp.)	15.5	17	9	.....	.....	.....
24-W 64″ T-6 (.1 Amp.)	12.5	10	7.5	.....	.....	.....
39-W 64″ T-6 (.2 Amp.)	22	17	12	.....	.....	.....
22-W 72″ T-8 (.1 Amp.)	12.5	10	7.5	.....	.....	.....
38-W 72″ T-8 (.2 Amp.)	22	17	12	.....	.....	.....
29-W 96″ T-8 (.1 Amp.)	.....	11.5	8	.....	.....	.....
51-W 96″ T-8 (.2 Amp.)	.....	19.5	14	.....	.....	.....
Mercury						
400-W A-H1	.....	40	27.5	.....	40	25
		230 Volts			460 Volts	
3000-W A-H9	.....	165	140	.....	135	125

Filament

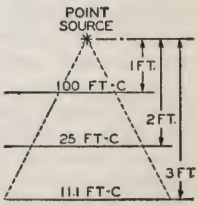
Watts	Bulb	Base	Finish	Rated Avg. Life (Hours)	Initial Lumens
General Service Lamps					
100	A–21	Med.	I.F.	750	1630
150	PS–25	Med.	I.F.–Cl.	750	2600
200	PS–30	Med.	I.F.–Cl.	750	3700
300	PS–30	Med.	I.F.–Cl.	750	5900
300	PS–35	Mogul	I.F.–Cl.	1000	5650
500	PS–40	Mogul	I.F.–Cl.	1000	9950
750	PS–52	Mogul	I.F.–Cl.	1000	15,500
1000	PS–52	Mogul	I.F.–Cl.	1000	21,500
1000	T–24	Med. Bipost	I.F.	1000	19,500
1500	PS–52	Mogul	I.F.–Cl.	1000	33,000
Projector and Reflector Lamps					
150	PAR–38	Med. Skt.	Projector Spot	1000	990 (0–15°)
150	PAR–38	Med. Skt.	Projector Flood	1000	1150 (0–30°)
150	R–40	Med.	Light Inside Frosted Reflector Spot	1000	700 (0–15°)
300	R–40	Med.		1000	1460 (0–15°)
150	R–40	Med.	Inside Frosted Reflector Flood	1000	700 (0–30°)
300	R–40	Med.		1000	1620 (0–30°)

Mercury

Watts	Bulb	Base	Desig-nation	Burning Hours Per Start	Rated Avg. Life (Hours)	Initial Lumens
400	T–16	Mogul	A–H1	5	4000	16,000
400	T–16	Mogul	A–H1	10	6000	16,000
3000	T–9½	S.C. Term.	A–H9	5	3000	120,000

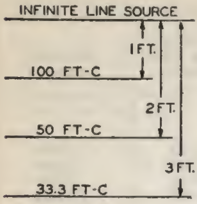
POINT-BY-POINT METHOD OF CALCULATION

Contrasted with the lumen method of calculation, which is based on the average light flux effective throughout an area, the point-by-point method is based on the actual amount of light which will be produced at specific points in the area. This requires a knowledge of the way in which light is distributed from sources of various shapes and sizes. The following basic relationships exist.



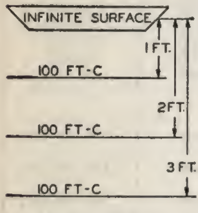
1. Point Source—Illumination is *inversely proportional to the square* of the distance (Inverse Square Law).

An incandescent lamp, alone or in an enclosing globe, can usually be treated as a point source.



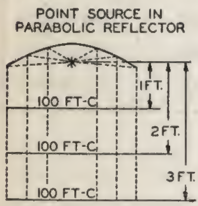
2. Line Source of Infinite Length—Illumination is *inversely proportional to* the distance.

A continuous row of fluorescent fixtures, or even one fluorescent lamp at short distance, approaches this condition. At sufficiently short distances from any linear source the footcandle values will be found to vary more nearly inversely with the first power, than with the square, of the distance.



3. Surface Source of Infinite Area—Illumination *does not change* with distance.

A large luminous panel, or a ceiling lighted by totally indirect means, approaches this condition, and within a certain distance range the illumination will not change greatly with distance.



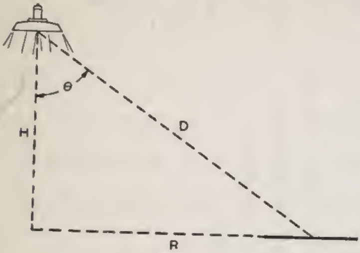
4. Parallel Beam of Light—Illumination *does not change* with distance.

A true point source in a perfect parabolic reflector would produce a parallel beam, but since any actual light source has finite dimensions, a completely parallel beam is never achieved. The inverse square law can be used to calculate the illumination from searchlights, spotlights, and other beam-producing devices beyond a certain minimum distance determined by the diameter and focal length of the reflector, and the size of the light source. Although the inverse-square distances for beam-producing equipment are substantially greater than those considered adequate for diffusing sources, they are still usually within the distance ranges at which these units are used.

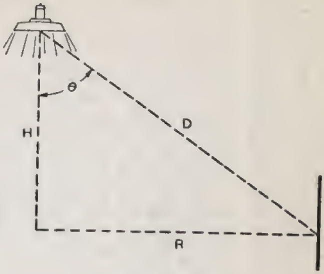
The present trend toward linear sources and continuous lines of light resulting from the increasing use of fluorescent lamps, as well as the growing popularity of lighted architectural elements, emphasizes the necessity for understanding the limitations of the inverse square law and recognizing the conditions under which it cannot correctly be used.

Theoretically, the inverse square law is based on a point light source radiating uniformly in all directions. Thus where the light source is an extended one, either a line of light or a large surface area, the point-by-point method cannot ordinarily be used to calculate the illumination for normal working distances. It can, however, be applied to any light source, provided the distance between the source and the illuminated surface is sufficiently great with respect to the size of the source. With diffusing light sources, five times the greatest dimension of the source is accepted in general practice as the minimum distance for which illumination can be calculated with reasonable accuracy.

Where these conditions are met, and the distribution curve of the source is available, it is possible to determine either horizontal or vertical surface illumination by using the following formulas:



Horizontal



Vertical

$$\text{Ft-c} = \frac{\text{Candlepower x } \cos \Theta}{\text{Distance squared}} \qquad \text{Ft-c} = \frac{\text{Candlepower x } \sin \Theta}{\text{Distance squared}}$$

Since sine $\Theta = \frac{R}{D}$ and cosine $\Theta = \frac{H}{D}$ the formulas may then be written in the following form:

$$\text{Ft-c (Horizontal Plane)} = \frac{\text{CP x H}}{D^3} \text{ or } \frac{\text{CP x } \cos^3 \Theta}{H^2}$$

$$\text{Ft-c (Vertical Plane)} = \frac{\text{CP x R}}{D^3} \text{ or } \frac{\text{CP x } \cos^2 \Theta \text{ x } \sin \Theta}{H^2}$$

To facilitate the calculation of horizontal footcandle intensities the table beginning on page 6—28 has been set up. It may be used by following three simple steps.

Step 1. Determine the angle in degrees from the upper figure in the table.

Step 2. From the distribution curve of the light source determine the candlepower of the source in that particular direction.

Step 3. Multiply the candlepower intensity by the multiplying factor, which is the lower figure in the table, and then divide the result by the candlepower (100 or 100,000) on which that part of the table is based. The answer thus obtained is the illumination in footcandles at that point.

The table on pages 6—28 and 6—29 may also be used to calculate footcandles on the vertical surface at a point in a plane which is normal to a vertical plane which includes the light source and the point. When the point is on a vertical surface which is not normal to the vertical plane containing the source and the point the additional angle must be considered.

POINT-BY-POINT FOOTCANDLE CALCULATION TABLE

Top figures—Angle between direction of light and vertical axis.
Bottom figures—Footcandles on the horizontal plane for the candlepower of the source in that direction.

Height of Light Source Above Surface—Feet	HORIZONTAL DISTANCE FROM AXIS OF LIGHT SOURCE—FEET																										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**35**	**40**	**50**
	FOOTCANDLES FOR EACH 100 CANDLEPOWER																										
2	0°0' 25.00	27° 17.85	45° 8.850	56° 4.275	63° 2.245	68° 1.298	71° .802	74° .528	76° .355	78° .255	79° .190	80° .142	81° .113	81° .090	82° .070	82° .058	83° .048	84° .038	84° .025	85° .020	85° .015	86° .013	86° .008	86° .007	87° .004	87° .000	87° .000
3	0°0' 11.11	18° 9.500	34° 6.400	45° 3.933	53° 2.400	59° 1.522	63° 1.000	67° .680	69° .477	72° .356	73° .264	75° .205	76° .161	77° .126	78° .100	79° .084	80° .070	81° .050	81° .036	82° .027	83° .021	83° .016	84° .012	84° .011	85° .007	86° .004	87° .002
4	0°0' 6.250	14° 5.707	27° 4.472	37° 3.200	45° 2.210	51° 1.524	56° 1.066	60° .764	63° .559	66° .419	68° .320	70° .249	72° .198	73° .159	74° .130	75° .107	76° .090	78° .064	79° .047	80° .037	81° .028	81° .022	82° .018	82° .015	84° .009	84° .006	86° .003
5	0°0' 4.000	11° 3.771	22° 3.202	31° 2.522	39° 1.904	45° 1.414	50° 1.050	54° .785	58° .595	61° .458	63° .358	66° .283	67° .228	69° .185	70° .152	72° .126	73° .106	74° .077	76° .057	77° .044	78° .034	79° .027	80° .022	81° .017	82° .010	83° .008	84° .004
6	0°0' 2.778	9° 2.673	18° 2.372	27° 1.987	34° 1.600	40° 1.260	45° .982	49° .766	53° .600	56° .474	59° .378	61° .305	63° .249	66° .205	67° .170	68° .142	69° .120	71° .088	73° .066	75° .051	76° .040	77° .032	78° .026	79° .021	80° .013	81° .009	83° .005
7	0°0' 2.041	8° 1.980	16° 1.814	23° 1.585	30° 1.336	36° 1.100	41° .893	45° .722	49° .583	52° .473	55° .385	58° .316	60° .261	62° .218	63° .183	65° .154	66° .131	69° .097	71° .074	72° .057	74° .045	75° .036	76° .029	77° .024	79° .016	80° .010	82° .006
8	0°0' 1.563	7° 1.527	14° 1.427	21° 1.283	27° 1.118	32° .953	37° .800	41° .672	45° .552	48° .458	51° .381	54° .318	56° .267	58° .225	60° .191	62° .163	63° .140	66° .105	68° .080	70° .063	72° .050	73° .040	74° .032	75° .026	77° .018	79° .012	81° .007
9	0°0' 1.235	6° 1.212	13° 1.148	18° 1.054	24° .943	29° .825	34° .711	38° .607	42° .515	45° .437	48° .370	51° .314	53° .267	55° .228	57° .196	59° .168	61° .146	63° .110	66° .085	68° .067	69° .053	71° .043	72° .035	73° .029	76° .019	77° .013	80° .008
10	0°0' 1.000	5°43' .985	11° .943	17° .879	22° .801	27° .716	31° .631	35° .550	39° .476	42° .411	45° .354	48° .305	50° .263	52° .227	54° .196	56° .171	58° .149	61° .115	63° .089	66° .071	67° .057	69° .046	70° .038	72° .032	74° .021	76° .014	79° .008
11	0°0' .826	5°12' .816	10° .787	15° .742	20° .686	24° .623	29° .559	32° .496	36° .437	39° .383	42° .335	45° .292	48° .255	50° .223	52° .195	54° .171	56° .150	59° .117	61° .092	63° .074	65° .060	67° .049	69° .040	70° .034	73° .023	75° .015	78° .009
12	0°0' .694	4°46' .687	9° .668	14° .634	18° .593	23° .546	27° .497	30° .448	34° .400	37° .356	40° .315	43° .278	45° .246	47° .217	49° .191	51° .169	53° .150	56° .119	59° .094	61° .076	63° .065	65° .051	67° .043	68° .036	71° .024	73° .017	77° .009
13	0°0' .592	4°24' .587	9° .571	13° .547	17° .517	21° .481	25° .447	28° .404	32° .366	35° .329	38° .295	40° .263	43° .235	45° .209	47° .187	49° .166	51° .148	54° .119	57° .096	59° .078	62° .064	63° .053	65° .044	67° .037	70° .025	72° .017	76° .010
14	0°0' .510	4°5' .506	8° .495	12° .477	16° .454	20° .426	23° .396	27° .365	30° .334	33° .304	36° .275	38° .248	41° .223	43° .201	45° .180	47° .162	49° .146	52° .118	55° .096	58° .079	60° .065	62° .054	63° .046	65° .039	68° .026	71° .018	75° .011
15	0°0' .444	3°49' .442	8° .433	11° .419	15° .401	18° .380	22° .356	25° .331	28° .305	31° .280	34° .256	36° .233	39° .212	41° .192	43° .174	45° .157	47° .142	50° .117	53° .096	56° .079	58° .066	60° .055	62° .047	63° .040	67° .027	69° .019	73° .011
16	0°0' .391	3°35' .388	7° .382	11° .371	14° .357	17° .339	21° .321	24° .300	27° .280	29° .259	32° .238	35° .219	37° .200	39° .183	41° .167	43° .152	45° .138	48° .115	51° .095	54° .080	56° .067	58° .056	60° .048	62° .041	66° .028	68° .020	72° .012
17	0°0' .346	3°22' .344	7° .339	10° .331	13° .319	16° .306	19° .290	22° .274	25° .256	28° .239	30° .222	33° .205	35° .189	37° .174	39° .159	41° .146	43° .134	47° .112	50° .094	52° .079	55° .069	57° .057	59° .048	60° .042	64° .029	67° .021	71° .012
18	0°0' .309	3°11' .307	6° .303	9° .297	13° .287	16° .276	18° .264	21° .250	24° .236	27° .221	29° .206	31° .192	34° .178	36° .165	38° .152	40° .140	42° .129	45° .109	48° .092	51° .079	53° .067	55° .057	57° .049	59° .042	63° .030	66° .021	70° .012
19	0°0' .277	3°1' .276	6° .273	9° .267	12° .260	15° .251	18° .240	20° .229	23° .217	25° .205	28° .192	30° .180	32° .167	34° .156	36° .145	38° .134	40° .124	43° .106	46° .090	49° .077	52° .066	54° .057	56° .049	58° .042	62° .030	65° .022	69° .013
20	0°0' .250	2°51' .249	5°43' .246	9° .242	11° .236	14° .228	17° .219	19° .210	22° .200	24° .190	27° .179	29° .168	31° .158	33° .147	35° .137	37° .128	39° .119	42° .103	45° .088	48° .076	50° .066	52° .057	54° .049	56° .043	60° .030	63° .022	68° .013

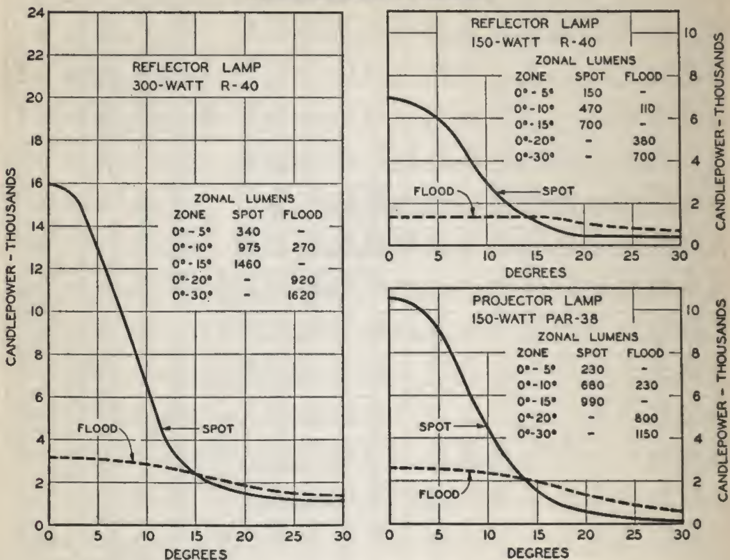
POINT-BY-POINT CALCULATION TABLE

Height of Light Source Above Surface—Feet																											
21	0°0' .227	2°44' .226	5°26' .224	8° .220	11° .215	13° .210	16° .201	18° .194	21° .185	23° .176	25° .167	28° .158	30° .144	32° .139	34° .131	36° .122	37° .114	41° .099	44° .086	46° .075	49° .065	51° .056	53° .049	55° .043	59° .031	62° .023	67° .014
22	0°0' .207	2°36' .206	5°10' .205	8° .201	10° .196	13° .192	15° .185	18° .179	20° .171	22° .164	25° .155	27° .148	29° .140	31° .132	33° .124	34° .114	36° .109	39° .096	42° .084	45° .073	47° .064	50° .056	52° .049	54° .043	58° .031	61° .023	66° .014
23	0°0' .189	2°29' .189	4°58' .187	7° .184	10° .181	12° .176	15° .171	17° .165	19° .159	21° .153	24° .146	26° .139	28° .132	29° .125	31° .118	33° .111	35° .105	38° .092	41° .081	44° .071	46° .063	49° .055	51° .049	53° .043	57° .031	60° .023	65° .014
24	0°0' .174	2°23' .173	4°45' .172	7° .170	10° .166	12° .163	14° .158	16° .154	18° .148	21° .143	23° .137	25° .130	27° .124	28° .118	30° .112	32° .106	34° .100	37° .089	40° .079	43° .070	45° .061	47° .054	49° .048	51° .042	56° .031	59° .024	64° .014
25	0°0' .160	2°17' .160	4°34' .158	7° .157	9° .154	11° .151	14° .147	16° .143	18° .138	20° .133	22° .128	24° .123	26° .117	27° .112	29° .106	31° .101	33° .096	36° .086	39° .076	41° .068	44° .060	46° .053	48° .047	50° .042	55° .031	58° .024	63° .015
27	0°0' .137	2°7' .137	4°14' .136	6° .135	8° .133	10° .130	12° .128	15° .124	17° .121	18° .117	20° .113	22° .109	24° .105	26° .100	27° .096	29° .092	31° .087	34° .079	37° .071	39° .064	42° .057	44° .051	46° .046	48° .041	52° .031	56° .024	62° .015
30	0°0' .111	1°54' .111	3°50' .111	5°43' .109	8° .108	9° .107	11° .105	13° .103	15° .100	17° .098	18° .095	20° .092	22° .089	23° .086	25° .083	27° .080	28° .077	31° .070	34° .064	36° .058	39° .053	41° .048	43° .043	45° .039	49° .031	53° .024	59° .015
33	0°0' .092	1°44' .092	3°28' .091	5°12' .091	7° .090	9° .089	10° .087	12° .086	14° .084	15° .082	17° .080	18° .078	20° .076	22° .074	23° .072	24° .069	26° .067	29° .062	31° .058	34° .053	36° .049	38° .045	40° .041	42° .037	47° .030	50° .024	57° .015
36	0°0' .077	1°36' .077	3°11' .077	4°46' .076	6° .076	8° .075	9° .074	11° .073	13° .072	14° .070	16° .069	17° .067	18° .066	20° .064	21° .062	23° .061	24° .059	27° .055	29° .052	31° .048	34° .044	36° .041	38° .038	40° .035	44° .029	48° .023	54° .015
40	0°0' .063	1°26' .062	2°52' .062	4°17' .062	5°43' .062	7° .061	9° .060	10° .060	11° .059	13° .058	14° .057	15° .056	17° .055	18° .054	19° .053	21° .051	22° .050	24° .047	27° .045	29° .042	31° .039	33° .037	35° .034	37° .032	41° .027	45° .022	51° .015
45	0°0' .049	1°16' .049	2°33' .049	3°49' .049	5°5' .049	6° .049	8° .048	9° .048	10° .047	11° .047	13° .046	14° .045	15° .045	16° .044	17° .043	18° .042	20° .041	22° .040	24° .038	26° .036	28° .034	30° .032	32° .030	34° .028	38° .025	42° .021	48° .013
50	0°0' .040	1°9' .040	2°17' .040	3°26' .040	4°34' .040	5°43' .039	7° .039	8° .039	9° .039	10° .038	11° .038	12° .037	14° .037	15° .036	16° .036	16° .035	18° .035	20° .033	22° .032	24° .031	26° .029	27° .028	29° .027	31° .025	35° .022	39° .019	45° .013
55	0°0' .033	1°2' .033	2°5' .033	3°7' .033	4°10' .033	5°9' .033	6° .032	7° .032	8° .032	9° .032	10° .032	11° .031	12° .031	13° .031	14° .030	15° .030	16° .029	18° .028	20° .027	22° .026	24° .025	25° .024	27° .023	29° .022	33° .020	36° .018	42° .013
60	0°0' .028	0°57' .028	1°55' .028	2°52' .028	3°50' .028	4°46' .027	5°43' .027	7° .027	8° .027	9° .027	9° .027	10° .026	11° .026	12° .026	13° .026	14° .025	15° .025	17° .024	18° .024	20° .023	22° .022	23° .021	25° .021	27° .020	30° .018	34° .016	40° .013
70	0°0' .020	0°49' .020	1°38' .020	2°34' .020	3°16' .020	4°5' .020	4°54' .020	5°43' .020	7° .020	7° .020	8° .020	9° .020	10° .020	11° .019	11° .019	12° .019	13° .019	14° .019	16° .018	17° .018	19° .017	20° .017	22° .016	23° .016	27° .015	30° .013	36° .011
	FOOTCANDLES FOR EACH 100,000 CANDLEPOWER																										
80	0°0' 15.63	0°43' 15.62	1°26' 15.61	2°9' 15.59	2°52' 15.57	3°35' 15.53	4°17' 15.49	5°0' 15.45	5°43' 15.39	6° 15.35	7° 15.27	8° 15.19	9° 15.09	9° 15.04	10° 14.93	11° 14.82	11° 14.75	13° 14.49	14° 14.27	15° 14.03	17° 13.71	18° 13.44	19° 13.16	21° 12.79	24° 12.02	27° 11.14	32° 9.531
100	0°0' 10.00	0°34' 9.999	1°9' 9.994	1°43' 9.987	2°17' 9.976	2°52' 9.963	3°26' 9.946	4°0' 9.927	4°34' 9.905	5°9' 9.880	5°43' 9.852	6° 9.826	7° 9.785	7° 9.761	8° 9.712	9° 9.660	9° 9.630	10° 9.539	11° 9.439	12° 9.330	14° 9.175	15° 9.048	16° 8.914	16° 8.819	19° 8.440	22° 7.993	27° 7.140
125	0°0' 6.400	0°28' 6.399	0°55' 6.398	1°22' 6.395	1°50' 6.390	2°17' 6.385	2°45' 6.378	3°12' 6.370	3°40' 6.361	4°7' 6.351	4°34' 6.339	5°2' 6.326	5°29' 6.313	6° 6.297	6° 6.286	7° 6.262	7° 6.250	8° 6.209	9° 6.163	10° 6.113	11° 6.059	12° 6.001	13° 5.938	14° 5.872	16° 5.708	18° 5.521	22° 5.120
150	0°0' 4.444	0°23' 4.444	0°46' 4.443	1°9' 4.442	1°32' 4.440	1°55' 4.437	2°17' 4.434	2°40' 4.430	3°2' 4.421	3°26' 4.416	3°49' 4.415	4°11' 4.409	4°34' 4.402	4°57' 4.395	5°20' 4.387	5°43' 4.379	6° 4.370	7° 4.349	8° 4.324	8° 4.309	9° 4.280	10° 4.249	11° 4.216	11° 4.195	13° 4.102	15° 4.008	19° 3.813
175	0°0' 3.265	0°20' 3.265	0°39' 3.265	0°59' 3.264	1°19' 3.263	1°38' 3.261	1°58' 3.260	2°17' 3.258	2°37' 3.255	2°57' 3.252	3°16' 3.249	3°36' 3.246	3°55' 3.242	4°15' 3.238	4°34' 3.234	4°54' 3.230	5°13' 3.225	6° 3.213	7° 3.199	7° 3.191	8° 3.174	8° 3.164	9° 3.145	10° 3.124	11° 3.076	13° 3.024	16 2.899
200	0°0' 2.500	0°17' 2.500	0°34' 2.500	0°52' 2.499	1°9' 2.499	1°26' 2.498	1°43' 2.497	2°0' 2.495	2°17' 2.494	2°35' 2.492	2°52' 2.490	3°9' 2.489	3°26' 2.487	3°43' 2.484	4°0' 2.482	4°17' 2.479	4°34' 2.476	5°9' 2.470	5°43' 2.463	6° 2.457	7° 2.446	7° 2.440	8° 2.428	9° 2.415	10° 2.390	11° 2.360	14° 2.282

Footcandles on the vertical surface—at a point that lies in a vertical plane which also includes the light source—may be determined by using the multiplying factor found when the table headings are reversed, i.e. the height of the light source is read on the horizontal distance scale, etc.

DISTRIBUTION DATA FOR REFLECTOR AND PROJECTOR LAMPS

CANDLEPOWER CURVES



FOOTCANDLE CURVES

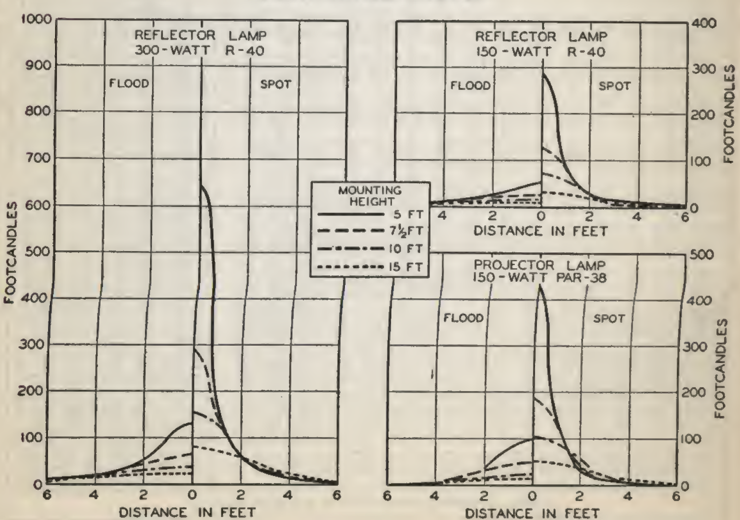


TABLE OF TRIGONOMETRIC FUNCTIONS

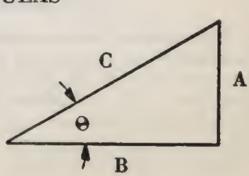
θ°	sin θ	cos θ	tan θ	cos² θ	cos³ θ	θ°	sin θ	cos θ	tan θ	cos² θ	cos³ θ
0	0.0000	1.000	0.0000	1.000	1.000	46	0.719	0.695	1.035	0.483	0.335
1	.0175	1.000	.0175	1.000	1.000	47	.731	.682	1.072	.465	.317
2	.0349	0.999	.0349	0.999	0.998	48	.743	.669	1.111	.448	.300
3	.0523	.999	.0524	.997	.996	49	.755	.656	1.150	.430	.282
4	.0698	.998	.0699	.995	.993	50	.766	.643	1.192	.413	.266
5	.0872	.996	.0875	.992	.989	51	.777	.629	1.235	.396	.249
6	.105	.995	.1051	.989	.984	52	.788	.616	1.280	.379	.233
7	.122	.993	.1228	.985	.978	53	.799	.602	1.327	.362	.218
8	.139	.990	.1405	.981	.971	54	.809	.588	1.376	.345	.203
9	.156	.988	.1589	.976	.964	55	.819	.574	1.428	.329	.189
10	.174	.985	.1763	.970	.955	56	.829	.559	1.483	.313	.175
11	.191	.982	.1944	.964	.946	57	.839	.545	1.540	.297	.162
12	.208	.978	.2126	.957	.936	58	.848	.530	1.600	.281	.149
13	.225	.974	.2309	.949	.925	59	.857	.515	1.664	.265	.137
14	.242	.970	.2493	.941	.913	60	.866	.500	1.732	.250	.125
15	.259	.966	.2679	.933	.901	61	.875	.485	1.804	.235	.114
16	.276	.961	.2867	.924	.888	62	.883	.470	1.881	.220	.103
17	.292	.956	.3057	.915	.875	63	.891	.454	1.963	.206	.0936
18	.309	.951	.3249	.905	.860	64	.899	.438	2.050	.192	.0842
19	.326	.946	.3443	.894	.845	65	.906	.423	2.144	.179	.0755
20	.342	.940	.3640	.883	.830	66	.914	.407	2.246	.165	.0673
21	.358	.934	.3839	.872	.814	67	.921	.391	2.356	.153	.0597
22	.375	.927	.4040	.860	.797	68	.927	.375	2.475	.140	.0526
23	.391	.921	.4245	.847	.780	69	.934	.358	2.605	.128	.0460
24	.407	.914	.4452	.835	.762	70	.940	.342	2.747	.117	.0400
25	.423	.906	.4663	.821	.744	71	.946	.326	2.904	.106	.0347
26	.438	.899	.4877	.808	.726	72	.951	.309	3.078	.0955	.0295
27	.454	.891	.5095	.794	.707	73	.956	.292	3.271	.0855	.0250
28	.470	.883	.5317	.780	.688	74	.961	.276	3.487	.0762	.0211
29	.485	.875	.5543	.765	.669	75	.966	.259	3.732	.0670	.0173
30	.500	.866	.5773	.750	.650	76	.970	.242	4.011	.0585	.0142
31	.515	.857	.6009	.735	.630	77	.974	.225	4.331	.0506	.0114
32	.530	.848	.6249	.719	.610	78	.978	.208	4.705	.0432	.0090
33	.545	.839	.6494	.703	.590	79	.982	.191	5.145	.0364	.0070
34	.559	.829	.6745	.687	.570	80	.985	.174	5.671	.0302	.0052
35	.574	.819	.7002	.671	.550	81	.988	.156	6.314	.0245	.0038
36	.588	.809	.7265	.655	.530	82	.990	.139	7.115	.0194	.0027
37	.602	.799	.7535	.638	.509	83	.993	.122	8.144	.0149	.0018
38	.616	.788	.7813	.621	.489	84	.995	.105	9.514	.0109	.0011
39	.629	.777	.8098	.604	.469	85	.996	.0872	11.430	.0076	.0007
40	.643	.766	.8391	.587	.450	86	.9976	.0698	14.300	.0048	.0003
41	.656	.755	.8693	.570	.430	87	.9986	.0523	19.081	.0027	.0001
42	.669	.743	.9004	.552	.410	88	.9994	.0349	28.636	.0012	.0000
43	.682	.731	.9325	.535	.391	89	.9998	.0175	57.290	.0003	.0000
44	.695	.719	.9656	.517	.372	90	1.0000	0.0000	Infinite	.0000	.0000
45	.707	.707	1.0000	.500	.354						

TRIGONOMETRIC FORMULAS

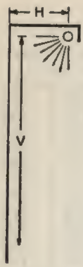
SINE $\theta = \frac{A}{C}$ COSINE $\theta = \frac{B}{C}$

TANGENT $\theta = \frac{A}{B}$ COTANGENT $\theta = \frac{B}{A}$

SECANT $\theta = \frac{C}{B}$ COSECANT $\theta = \frac{C}{A}$



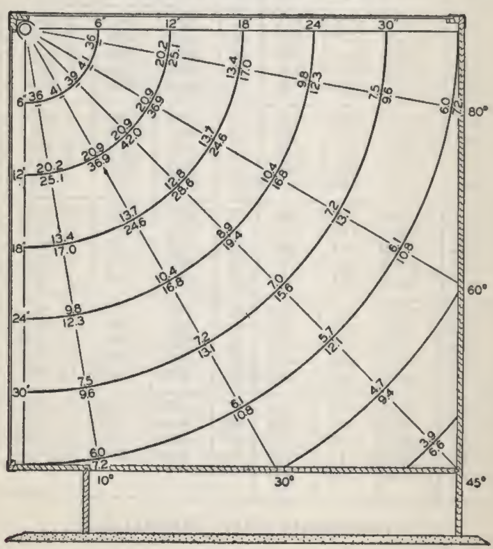
WALL CASE AND VALANCE LIGHTING



	Horizontal Distance—H							
	Values with Symmetrical Reflector				Values without Reflector			
Vertical Distance—V	6″	12″	18″	24″	6″	12″	18″	24″
6″	21.4	15.7	12.1	9.8	30.6	22.8	16.5	13.5
12″	12.0	12.8	12.1	10.2	11.3	14.7	13.6	12.2
18″	7.4	9.6	10.0	9.1	5.2	8.8	10.2	9.6
24″	4.4	6.9	8.8	7.7	2.6	5.0	6.6	7.2
30″	2.6	4.8	6.9	6.8	1.4	3.3	4.4	5.2
36″	2.0	3.8	5.2	6.1	1.0	2.2	3.2	4.1
42″	1.4	2.8	4.1	5.0	0.6	1.4	2.2	3.0
48″	0.8	1.9	2.8	4.1	0.4	1.0	1.6	2.2
54″	0.8	1.6	2.4	3.4	0.4	0.8	1.4	1.6
60″	0.6	1.2	1.9	2.6	0.3	0.8	1.0	1.4

The above table lists the approximate illumination in footcandles produced by fluorescent lamps on a vertical surface for each 100 rated lamp lumens per foot of case length. The specular symmetrical reflector was so adjusted that its maximum candlepower was directed at a point 42″ below the lamp. Where no reflector was used the entire inner surface of the valance was painted white.

SHOWCASE LIGHTING



The above sketch indicates the approximate initial footcandles perpendicular to the source at various angles for each 100 rated lamp lumens per foot of case length. The figures above the arcs represent footcandles obtained with a fluorescent lamp in a specular showcase reflector. The figures below the arcs represent footcandles obtained with standard filament reflector showcase lamps, and differ from the fluorescent values because of beam control.

CHAPTER SEVEN

INTERIOR WIRING FOR LIGHTING

The principal requirements of any satisfactory wiring installation are those of safety and adequacy. The National Electrical Code* and various local codes are written to provide safety; however, adequacy does not necessarily follow as a direct result of meeting the requirements for safety. When planning an installation provision should be made for reasonable future additions to the system and for flexibility in its use.

REQUIREMENTS FOR SAFETY IN WIRING

A wire can carry only a certain amount of electric current without becoming overheated. This amount will vary, depending upon the cross-sectional area of the wire, the composition of the insulating material covering it, and the number of wires enclosed in a tube or conduit. The principal types of insulation available for building wires and their uses and limitations are given in the following table.

CLASSIFICATION AND USES OF BUILDING WIRE

Trade Name	Type Letter	Max. Operating Temp.	Special Provisions
Code Rubber	R	60C 140F	General use.
Heat-Resistant Rubber	RH	75C 167F	General use.
Moisture-Resistant Rubber	RW	60C 140F	General use and wet locations.
Latex Rubber	RU	60C 140F	General use.
Thermoplastic	T	60C 140F	General use. No. 14 to 4/0 inclusive. Open work No. 14 to 2,000,000 C.M.
Moisture-Resistant Thermoplastic	TW	60C 140F	General use and wet locations. No. 14 to 4/0 inclusive. Open work No. 14 to 2,000,000 C.M.

* All references to the National Electrical Code in this Chapter, including wire sizes, designations, and capacities, are based on the 1947 revision.

CLASSIFICATION AND USES OF BUILDING WIRE—Continued			
Trade Name	**Type Letter**	**Max. Operating Temp.**	**Special Provisions**
Thermoplastic and Asbestos	TA	90C 194F	Switchboard wiring only.
Varnished Cambric	V	85C 185F	Dry locations only. Smaller than No. 6 by special permission.
Asbestos and Varnished Cambric	AVA	110C 230F	Dry locations only.
Asbestos and Varnished Cambric	AVL	110C 230F	Wet locations.
Asbestos and Varnished Cambric	AVB	90C 194F	Dry locations only.
Asbestos	A	200C 392F	Dry locations only. Not for general use. In raceways, only for leads to or within apparatus. Limited to 300 V.
Asbestos	AA	200C 392F	Dry locations only. Open wiring. Not for general use. In raceways, only for leads to or within apparatus. Limited to 300 V.
Asbestos	AI	125C 257F	Dry locations only. Not for general use. In raceways, only for leads to or within apparatus. Limited to 300 V.
Asbestos	AIA	125C 257F	Dry locations only. Open wiring. Not for general use. In raceways, only for leads to or within apparatus.
Paper		85C 185F	For underground service conductors, or by special permission.
Slow-Burning	SB	90C 194F	Dry locations only. Open wiring; and in raceways where temperatures will exceed those permitted for rubber-covered or varnished cambric-covered conductors.
Slow-Burning Weatherproof	SBW	90C 194F	Dry locations only. Open wiring only.
Weatherproof	WP	80C 176F	Open wiring by special permission where other insulations are not suitable for existing conditions.

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Not More Than Three Conductors in Raceway or Cable

(Based on Room Temperature of 30°C, 86°F)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) / Thermoplastic Type T (14–4/0) Type TW (14–4/0)	Rubber Type RH	Paper / Thermoplastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impregnated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	270	315	335	...
300	240	285	300	345	380	...
350	260	310	325	390	420	...
400	280	335	360	420	450	...
500	320	380	405	470	500	...
600	355	420	455	525	545	...
700	385	460	490	560	600	...
750	400	475	500	580	620	...
800	410	490	515	600	640	...
900	435	520	555	...	...	...
1,000	455	545	585	680	730	...
1,250	495	590	645	...	...	...
1,500	520	625	700	785	...	...
1,750	545	650	735	...	...	...
2,000	560	665	775	840	...	...

Correction Factors for Room Temperatures Over 30°C, 80°F

°C	°F						
40	104	.82	.88	.90	.94	.95	
45	113	.71	.82	.85	.90	.92	
50	122	.58	.75	.80	.87	.89	
55	131	.41	.67	.74	.83	.86	
60	140		.58	.67	.79	.83	.91
70	158		.35	.52	.71	.76	.87
75	167			.43	.66	.72	.86
80	176			.30	.61	.69	.84
90	194				.50	.61	.80
100	212					.51	.77
120	248						.69
140	284						.59

More Than Three Conductors in a Raceway

The preceding table gives the allowable current-carrying capacity for not more than three conductors in a raceway or cable. If the number of conductors in a raceway or cable is from 4 to 6, the allowable current-carrying capacity of each conductor shall be reduced to 80 per cent of the values in the table. If the number of conductors in a raceway or cable is from 7 to 9, the allowable current-carrying capacity of each conductor shall be reduced to 70 per cent of the values in the table.

CONDUIT SIZE Rubber-Covered Types RF-32, R, RH, RW and RU Thermoplastic Types TF, T and TW (One to Nine Conductors)									
Size AWG MCM	Number of Conductors in One Conduit or Tubing								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	*1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1½	1½	2	2½	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	4½
300	1¼	2½	2½	3	3½	4	4	4½	4½
350	1¼	3	3	3½	3½	4	4½	4½	5
400	1½	3	3	3½	4	4	4½	5	5
500	1½	3	3	3½	4	4½	5	5	6
600	2	3½	3½	4	4½	5	6	6	6
700	2	3½	3½	4½	5	5	6	6	...
750	2	3½	3½	4½	5	6	6	6	...
800	2	3½	4	4½	5	6	6	...	...
900	2	4	4	5	6	6	6	...	...
1000	2	4	4	5	6	6	...	...	...
1250	2½	4½	4½	6	6	...	...	...	...
1500	3	5	5	6	...	...	...	...	...
1750	3	5	6	6	...	...	...	...	...
2000	3	6	6	...	...	...	...	...	...

* Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end, two number 4 insulated and one number 4 bare conductors may be installed in 1-inch conduit or tubing.

POWER FACTOR AND LINE CURRENT

The total power in any direct-current circuit or in any alternating-current circuit with only resistance loads, such as filament lamps, may be expressed by the fundamental equation:

$$\text{Total Watts} = \text{Volts} \times \text{Amperes} \qquad (1)$$

In such circuits the total watts are *active* in doing useful work; that is, in heating the filament to incandescence.

Electric discharge lamps such as fluorescent lamps and mercury vapor amps require ballasts to limit the current to rated values. Since these ballasts are not pure resistance loads, some of the current flowing in the circuit is not effective in the operation of the ballast or in the production of light.

In these circuits the product of volts and amperes is not equal to the active watts as read by a wattmeter because such a meter measures only the active power used. It is therefore necessary to use a different equation to express the active watts in such a circuit.

$$\text{Total Watts (active)} = \text{Volts} \times \text{Amperes} \times \text{Power Factor}$$

$$\text{or Amperes} = \frac{\text{Total Watts (active)}}{\text{Volts} \times \text{Power Factor}} \qquad (2)$$

Power Factor, therefore, is the ratio of the *active power* (as read on the wattmeter) to the product of the volts and amperes (as read on meters placed in the circuit). This ratio is usually expressed in percentage.

$$\text{Power Factor} = \frac{\text{Total Watts (active)}}{\text{Amperes} \times \text{Volts}} \qquad (3)$$

From equation (2), it is readily seen how the power factor affects the total current in a circuit. When the power factor is 100%, the current is at a minimum and the product of the amperes and volts is equal to the active watts as measured by a wattmeter. If the power factor is 50%, the current in the circuit is doubled; if it is 80%, the current will be increased by 25%, etc.

As an illustration of the effect of power factor, assume that a load of 2400 watts at 100% power factor is connected to a 120-volt circuit. Under these conditions the current would be 20 amperes and would require at least number 12 type R wire. If, however, a 2400-watt load with 80% power factor were connected to the same circuit, 25 amperes would be drawn and number 10 wire would be required. Thus, in determining the size of wire required, it is necessary to know the power factor as well as the wattage of the load. Failure to consider the effect of power factor on the current, especially when the circuits are heavily loaded, may result in overheated wires, excessive voltage drop, or interruptions caused by the operation of protective equipment.

SELECTION OF FEEDER AND BRANCH CIRCUIT WIRE SIZES

1. Determine length of run

Length of run of a feeder circuit (one wire length only) is considered the distance from the service entrance to the branch panelboard. For a branch circuit, it is the distance from the panelboard to the outlet at or nearest the center of the branch circuit load. In cases where outlets on the same branch circuit are widely separated, it may be necessary to calculate the drop for each individual outlet.

2. Calculate the wattage or ampere load

When incandescent lamps are employed, the total wattage of the sources fed by a particular circuit is the sum of the individual lamp wattages. When the load includes mercury vapor or fluorescent lamps, the total wattage is the sum of the lamp wattages plus the sum of the ballast losses. In the latter case it is more accurate to determine the load in terms of amperes (formula 2 on page 7—5) thereby taking into account the power factor of the equipment.

3. Determine wire size from following table

The wire size necessary to provide adequate voltage at the lamp will vary with the total current in the circuit and the length of run. The table on the following page indicates the wire size necessary to service various loads with a specific voltage drop.

Wiring sizes should be sufficient to carry the required current to its point of utilization with the minimum voltage drop consistent with economical operation of the lighting system. The allowable drop from an economic standpoint varies somewhat depending upon the equipment being served, but a practical as well as an economic limit for lighting installations is a 2% drop from panelboard to the center of the load. Feeder circuits should be limited to a maximum drop of 1%.

This is a general rule, however, since physical conditions may alter the design. It is well to limit the total voltage drop under full load, where practical, to 3% of line voltage from the mains to branch circuit load centers.

Example

To find the size of wire required for a branch circuit 60 feet long having a load of 1300 watts and connected to a 115-volt circuit, turn to the table on page 7—7; opposite 1380 (the value nearest to 1300) and below a length of run of 60 feet will be found 10, which is the wire size required.

BRANCH CIRCUIT AND FEEDER WIRE SIZES FOR VARIOUS LENGTHS OF RUN

On short runs, where voltage drop does not affect wire size, the table shows minimum permissible commercial size Brown & Sharpe gauge rubber-covered copper wire according to the National Electrical Code.

Based on { **Two Per Cent Loss in Voltage on 115-volt, 2-wire circuits.**
One Per Cent Loss in Voltage on 220-volt, 2-wire circuits.
One Per Cent Loss in Voltage on 115/230-volt, 3-wire circuits.

Wattage Load 115-Volt Circuit	Amp. Load	Length of Run in Feet																	
		30	40	50	60	70	80	90	100	120	140	160	180	200	240	280	320	360	400
575	5	14	14	14	14	14	14	12	12	12	10	10	10	10	8	8	8	6	6
690	6	14	14	14	14	14	12	12	12	10	10	10	8	8	8	8	6	6	6
805	7	14	14	14	14	12	12	12	10	10	10	8	8	8	6	6	6	6	4
920	8	14	14	14	12	12	12	10	10	10	8	8	8	8	6	6	6	4	4
1,035	9	14	14	12	12	12	10	10	10	8	8	8	8	6	6	6	4	4	4
1,150	10	14	14	12	12	10	10	10	10	8	8	8	6	6	6	4	4	4	4
1,380	12	14	12	12	10	10	10	8	8	8	8	6	6	6	4	4	4	4	2
1,610	14	14	12	10	10	10	8	8	8	6	6	6	6	4	4	4	2	2	2
1,840	16	12	12	10	10	8	8	8	8	6	6	6	4	4	4	2	2	2	2
2,070	18	12	10	10	8	8	8	8	6	6	6	4	4	4	4	2	2	2	1
2,300	20	12	10	10	8	8	8	6	6	6	4	4	4	4	2	2	2	1	1
2,875	25	10	10	8	8	6	6	6	6	4	4	4	2	2	2	1	1	0	0
3,450	30	8	8	8	6	6	6	6	4	4	4	2	2	2	1	1	0	0	2/0
4,025	35	8	8	6	6	6	4	4	4	4	2	2	2	1	1	0	2/0	2/0	3/0
4,600	40	6	6	6	6	4	4	4	4	2	2	2	1	1	0	2/0	2/0	3/0	3/0
5,175	45	6	6	6	6	4	4	4	2	2	2	1	1	0	2/0	2/0	3/0	3/0	4/0
5,750	50	6	6	6	4	4	4	2	2	2	1	1	0	0	2/0	3/0	3/0	4/0	4/0
6,900	60	4	4	4	4	4	2	2	2	1	1	0	0	2/0	3/0	3/0	4/0	4/0	
8,050	70	4	4	4	4	2	2	2	1	1	0	2/0	2/0	3/0	3/0	4/0	4/0		
9,200	80	2	2	2	2	2	2	1	1	0	2/0	2/0	3/0	3/0	4/0	4/0			
10,350	90	2	2	2	2	2	1	1	0	2/0	2/0	3/0	3/0	4/0	4/0				
11,500	100	1	1	1	1	1	1	0	0	2/0	3/0	3/0	4/0	4/0					
13,800	120	0	0	0	0	0	0	0	2/0	2/0	3/0	4/0	4/0						

NOTE: For good voltage regulation design feeders for a maximum of one per cent voltage drop, branch circuits for a maximum of two per cent voltage drop.

Where wire larger than 10 is required to eliminate excessive voltage drop on branch circuits, split the circuits, or move the panel board closer to the load center.

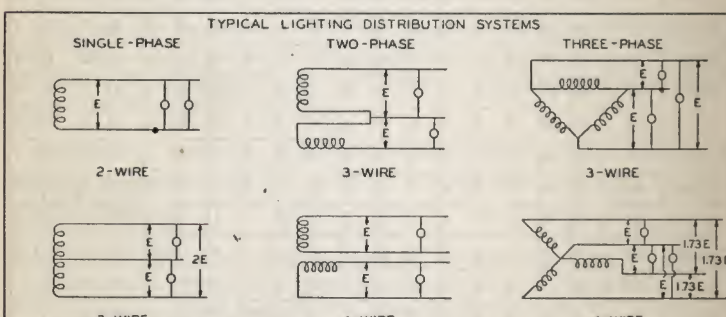
Length of Run is the one-way distance from source of supply to panel or from panel to outlet. The length of wire required between these points is double this distance for 2-wire circuits and three times this distance for 3-wire circuits.

FORMULAS FOR DETERMINING AMPERES, KW AND KVA				
To Find	Direct Current	Single-Phase	Two-Phase* 4-Wire	Three-Phase**
Amperes when Horsepower is known	$\frac{Hp \times 746}{E \times \%Eff}$	$\frac{Hp \times 746}{E \times \%Eff \times PF}$	$\frac{Hp \times 746}{2E \times \%Eff \times PF}$	$\frac{Hp \times 746}{1.73E \times \%Eff \times PF}$
Amperes when Kilowatts are known	$\frac{Kw \times 1000}{E}$	$\frac{Kw \times 1000}{E \times PF}$	$\frac{Kw \times 1000}{2 \times E \times PF}$	$\frac{Kw \times 1000}{1.73 \times E \times PF}$
Amperes when Kva are known		$\frac{Kva \times 1000}{E}$	$\frac{Kva \times 1000}{2 \times E}$	$\frac{Kva \times 1000}{1.73 \times E}$
Kilowatts	$\frac{E \times I}{1000}$	$\frac{E \times I \times PF}{1000}$	$\frac{E \times I \times 2 \times PF}{1000}$	$\frac{E \times I \times 1.73 \times PF}{1000}$
Kva		$\frac{E \times I}{1000}$	$\frac{E \times I \times 2}{1000}$	$\frac{E \times I \times 1.73}{1000}$

I = Total Amperes E = Volts %Eff = per cent efficiency PF = Power Factor
Kw = Kilowatts Kva = (Kilovolt-amperes) Hp = Horsepower

* For two-phase 3-wire circuits the current in the common conductor is 1.41 times that in either of the two other conductors.

** In a three-phase 4-wire Y (wye) connected system, the phase-to-phase voltage is equal to 1.73 times the phase-to-neutral voltage. In a three-phase 4-wire △ (delta) connected system the phase-to-phase voltage is twice the phase-to-neutral voltage.



WIRING SUGGESTIONS

Panelboards

1. Branch circuit panelboards should, where possible, be located at or near the load center.

2. Good practice requires that a spare circuit be added for each five active circuits to provide for future load.

3. Circuit-breaker panelboards have the advantage of greater convenience and simplicity of operation. They also afford switch control of branch circuits.

Convenience Outlets

In commercial installations it is always desirable to segregate convenience outlet branch circuits from the lighting circuits. Spacing and num-

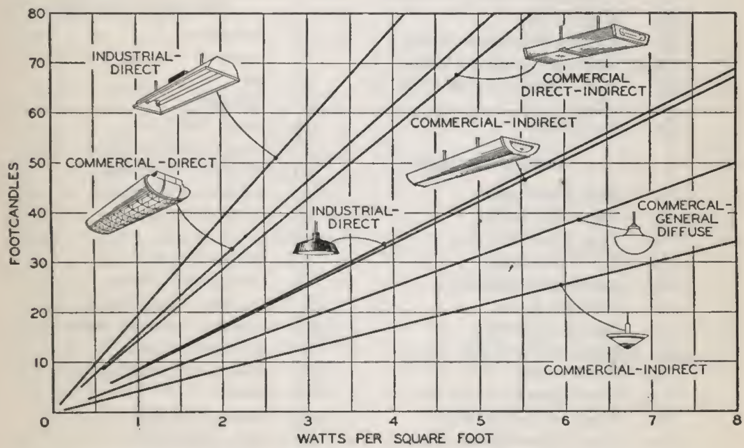
ber of outlets per circuit will be determined by the nature of the electrical requirements. For example, an electrical appliance store will require many more convenience outlets and greater capacity than a grocery store. The minimum number of outlets for the sales area of a store is one outlet per 400 square feet of floor space. For the show windows, one outlet for every 50 square feet of window floor space is the accepted minimum. Ceiling receptacles should be considered when designing show window wiring.

In general office areas, wall convenience outlets should be spaced not more than 20 feet apart, and in private offices not more than 10 feet apart. Outlets in offices are usually placed in the wall or columns above the baseboard except where machines in the center of the room require outlets in the floor.

Manufacturing areas should have at least one outlet for every 20 linear feet of wall space or one outlet per bay (approximately 400 sq. ft.); normally outlets are located for specific machines or operations.

ESTIMATING THE CAPACITY OF A NEW WIRING INSTALLATION

In a new building, wiring is sometimes installed before the lighting layout has been definitely established. It is, of course, desirable to have specific information as to the total lighting load before designing the wiring, but when the lighting arrangements are not settled, the procedure below may be followed. This method should be used for rough wiring estimating only and should not be substituted for actual layout and load computations.



(1) Determine the desired level of illumination for the area by reference to Chapter Five.

(2) On the curve above, follow the horizontal line, beginning at the maintained footcandle value selected in (1), until it intersects the curve corresponding to the fixture type to be installed. Read the watts per sq. ft. required on the scale directly below the intersection point.

This chart is for the average room. For large rooms higher footcandle values may be expected—for small rooms lower values will result.

STANDARD WIRING SYMBOLS

GENERAL OUTLETS

Ceiling	Wall	
○	-○	Outlet.
Ⓑ	-Ⓑ	Blanked Outlet.
Ⓓ		Drop Cord.
Ⓔ	-Ⓔ	Electrical Outlet; for use only when circle used alone might be confused with columns, plumbing symbols, etc.
Ⓕ	-Ⓕ	Fan Outlet.
Ⓙ	-Ⓙ	Junction Box.
Ⓛ	-Ⓛ	Lamp Holder.
$Ⓛ_{PS}$	$-Ⓛ_{PS}$	Lamp Holder with Pull Switch.
Ⓢ	-Ⓢ	Pull Switch.
Ⓥ	-Ⓥ	Outlet for Vapor Discharge Lamp.
ⓧ	-ⓧ	Exit Light Outlet.
Ⓒ	-Ⓒ	Clock Outlet. (Specify Voltage)

CONVENIENCE OUTLETS

	Duplex Convenience Outlet.
$_{1,3}$	Convenience Outlet other than Duplex. 1 - Single, 3 - Triplex, etc.
$_{WP}$	Weatherproof Convenience Outlet.
$_{R}$	Range Outlet.
$_{S}$	Switch and Convenience Outlet.
$\boxed{R}$	Radio and Convenience Outlet.
	Special Purpose Outlet. (Des. in Spec.)
	Floor Outlet.

SWITCH OUTLETS

S	Single Pole Switch.
S_2	Double Pole Switch.
S_3	Three Way Switch.
S_4	Four Way Switch.
S_D	Automatic Door Switch.
S_E	Electrolier Switch.
S_K	Key Operated Switch.
S_P	Switch and Pilot Lamp.
S_{CB}	Circuit Breaker.
S_{WCB}	Weatherproof Circuit Breaker.
S_{MC}	Momentary Contact Switch.
S_{RC}	Remote Control Switch.
S_{WP}	Weatherproof Switch.
S_F	Fused Switch.
S_{WF}	Weatherproof Fused Switch.

PANELS, CIRCUITS, AND MISCELLANEOUS

	Lighting Panel.
	Power Panel.
	Branch Circuit; Concealed in Ceiling or Wall.
	Branch Circuit; Concealed in Floor.
	Branch Circuit; Exposed.
	*Home Run to Panel Board. Indicate number of Circuits by number of arrows.
	Feeders.
	**Underfloor Duct and Junction Box.
	Battery.
Ⓖ	Generator.
Ⓜ	Motor.
Ⓘ	Instrument.
Ⓣ	Power Transformer. (Or draw to scale.)
	Controller.
	Isolating Switch.

AUXILIARY SYSTEMS

	Push Button.
	Buzzer.
	Bell.
	Annunciator
	Outside Telephone.
	Interconnecting Telephone.
	Telephone Switchboard.
	Bell Ringing Transformer.
$\boxed{D}$	Electric Door Opener.
	Fire Alarm Bell.
$\boxed{F}$	Fire Alarm Station.
	City Fire Alarm Station.
$\boxed{FA}$	Fire Alarm Central Station.
$\boxed{FS}$	Automatic Fire Alarm Device.
$\boxed{W}$	Watchman's Station.
	Watchman's Central Station.
$\boxed{H}$	Horn.
$\boxed{N}$	Nurse's Signal Plug.
$\boxed{M}$	Maid's Signal Plug.
$\boxed{R}$	Radio Outlet.
$\boxed{SC}$	Signal Central Station.
	Interconnection Box.

*Any circuit without further designation indicates a two-wire circuit. For a greater number of wires indicate as follows: -///- (3 wires) -////- (4 wires), etc.

**For double or single systems eliminate one or two lines. This symbol is equally adaptable to auxiliary system layouts.

CHAPTER EIGHT

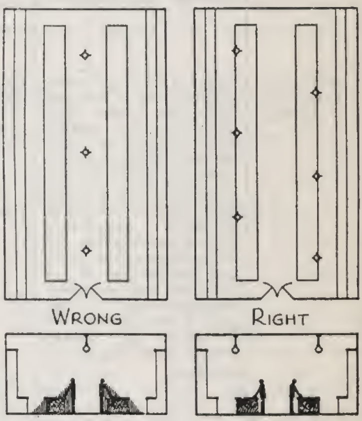
STORE, OFFICE, SCHOOL, AND PUBLIC BUILDING LIGHTING

LIGHT FOR MERCHANDISING

Lighting in stores must provide something more than footcandles to permit inspection of merchandise on display without customer eyestrain. It should also create an appropriate atmosphere as a part of the store interior design, and it should serve as a silent salesman in attracting customer attention to displays for the purpose of stimulating "impulse" buying and directing store traffic. Stores so lighted contribute something more to better merchandising: they are pleasant and attractive places in which to work, thereby improving employee morale and selling efficiency.

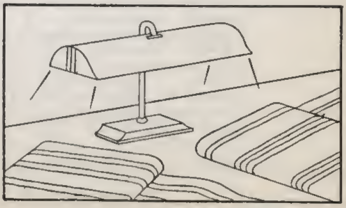
GENERAL LIGHTING DESIGN NOTES

A single row of enclosing globes through the center of the usual store (see sketch) will result in bad shadows on counters and displays. Two rows spaced properly over the counters are preferred. In small narrow stores, one row of efficient indirect lighting fixtures may be used if the store type permits from a merchandising standpoint.



Lighting Can Change the Apparent Dimensions of a store. Long ceiling panels or coves extending from the front to the back of a room add to its apparent length; recessed or flush mounted ceiling units increase the apparent ceiling height, as do vertical luminous architectural elements on columns and side walls; pendant indirect troughs, urns, and coves lower the apparent ceiling height; and architectural panels or coves located across a long store will give the effect of shortening its length.

"Color Matching" Lighting for large merchandising areas or for counters is frequently required in stores. For large areas, Daylight fluorescent lamps provide an approximate approach to outdoor light and are a practical solution, although their spectrum lacks deep red which color matching sources should have if the matching is very critical. Daylight



LIGHTING SUGGESTIONS FOR THE PRINCIPAL STORE TYPES

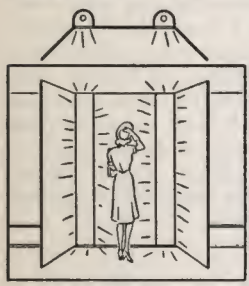
Store Types	Merchandising Characteristics	Typical Examples	Suggested Lighting
Stores with *Location Appeal*	Purchases are made quickly; "impulse" buying is a factor. Decoration is usually plain with little relationship to the merchandise on display.	Cigar Store, Refreshment Stand, Stationery Store, Luncheonette etc.	High levels of general illumination throughout the entire interior is the basic need. Semi-direct, semi-indirect, or direct-indirect fixtures are recommended. The lighting installations should be efficient; fixtures should be closely spaced and easily cleaned and relamped. Decorative lighting should be considered secondary from the selling standpoint.
Stores with *Acceptance Appeal*	Regular and frequent purchases are the rule. "Impulse" buying is a big factor in creating sales volume. Cleanliness must be readily apparent. Attractive displays of the merchandise are essential.	Neighborhood Grocer, Druggist, Delicatessen, Fish Market, etc.	Efficient, but inornate direct-indirect fixtures should be closely spaced to provide high level illumination throughout the interior. When ceilings are low, flush mounted down lights combined with indirect lighting from top of wall shelves may be used. Spot lighting of displays is important. (See Display Lighting). Colored lighting on displays should be used with restraint.
Stores with *Prestige Appeal*	Stores of this type usually have been in business for many years; their reputation for quality and service is well known. They may specialize in only one line of merchandise or many lines; they may be large or small. Appearance of the merchandise, the atmosphere of the store, and the comfort of the customer are important considerations. "Impulse" buying must be stimulated by display design and lighting novelty.	Department Stores, Clothing Shops, Furniture Stores, Rug Merchants, etc.	The general illumination should be in the order of 20—30 foot-candles in the circulating areas, and 50 or above in the merchandising areas. *Down lighting* over counters and displays is appropriate when combined with general illumination. Pendant type semi-indirect and direct fixtures, indirect pedestal units, and architectural built-in designs on ceiling or walls are recommended for general lighting; prismatic lens or louvered down lighting from recessed or ceiling type units is suitable for high lighting the merchandise. Wall cases, show cases, and all free-standing or special displays should be lighted. Colored lighting of displays should be considered and equipment provided.
Stores with *Eye Appeal*	In this group, the stores are of the specialty type, selling unusual and imported merchandise at prices above the usual level. "Impulse" buying is relied upon extensively. Merchandise must be displayed in novel ways to catch the eye. Decoration and atmosphere are necessary to a high degree.	Jewelry Stores, Exclusive Dress Shops, Accessory Shops, Gift Shops, Fur Stores, Specialty Shops of various kinds	As in the "Prestige" type, high level illumination in display areas combined with general illumination from decorative fixtures or architectural units is required. Colors of merchandise may be enhanced by clever use of tinted lighting on displays. All cases and special displays should be high lighted. Recessed or flush mounted ceiling spot lights and other special high lighting equipment should be considered in the interest of better appearance.

blue incandescent lamps, or general service incandescent lamps equipped with color screens specially designed to simulate daylight can be used. Counter-type "matching" units using the Daylight fluorescent lamp have provided a convenient and economical solution to this problem, except in those instances where very critical color matching is necessary.

Brilliant sparkle of stones in jewelry stores **requires a source of light with a small concentrated filament of high brightness, such as the incandescent lamp. Displays of stones should, therefore, be illuminated with incandescent sources primarily, but where possible Daylight fluorescent lamps in addition to the filament lamps will improve the color and add to the effectiveness of the display.**

Fading of pigments by artificial light, **regardless of the type of light source (filament or fluorescent lamps) depends upon the time of exposure and the intensity of the lighting, provided the dye and the atmospheric conditions are the same in each case.**

Fitting Mirror Lighting **should light the person and garment under inspection and not the mirror. Vertical illumination must be high without glare. Well shielded (louvered or covered with opal glass) vertical luminous panels or coves on each side of the mirror, combined with overhead lighting, are recommended. Typical designs are illustrated in the sketches. (a), (b), (c).**



Vertical luminous panels combined with indirect lighting from unit on wall over center mirror.

(a)

Light sources concealed back of mirror indirectly lighting ceiling and wall space on each side of mirror. Vertical illumination is high in this design.

(b)

Prismatic control lens directs the light on the vertical from a special light box attached to wall above the central mirror.

(c)

DISPLAY LIGHTING DESIGN NOTES

The functions of display lighting are:

1. **To make a display easily and quickly visible.**
2. **To compel customer attention to the merchandise.**
3. **To contribute novelty and color.**

The importance of these three functions of light in the art and science of selling is well recognized by leading merchandisers.

The factors influencing the design of display lighting are as follows:

1. **Time**—High levels of illumination are necessary for quick vision followed by lasting mental impressions of the merchandise on display. Modern living at high speed reflects in the average customer's allotment of time for shopping, making high level display lighting necessary for full selling effectiveness.

2. **Size**—Light magnifies detail, and the smaller and more intricate the display, the higher the illumination level should be to create interest and attract attention.

3. **Contrast**—Dark objects displayed against light backgrounds are several hundred times more easily seen than against a dark background by virtue of the greater contrast. Lighting equipment must be available to permit the display man to vary illumination levels to take advantage of contrast in his displays, or to make up for lack of contrast with greater brightness.

4. **Brightness**—The eye is definitely attracted by the brightest objects in its visual field—displays in stores or show windows must, therefore, be high-lighted with respect to their immediate surroundings. Flexible lighting systems permitting variations in brightness and color should always be provided by the engineer.

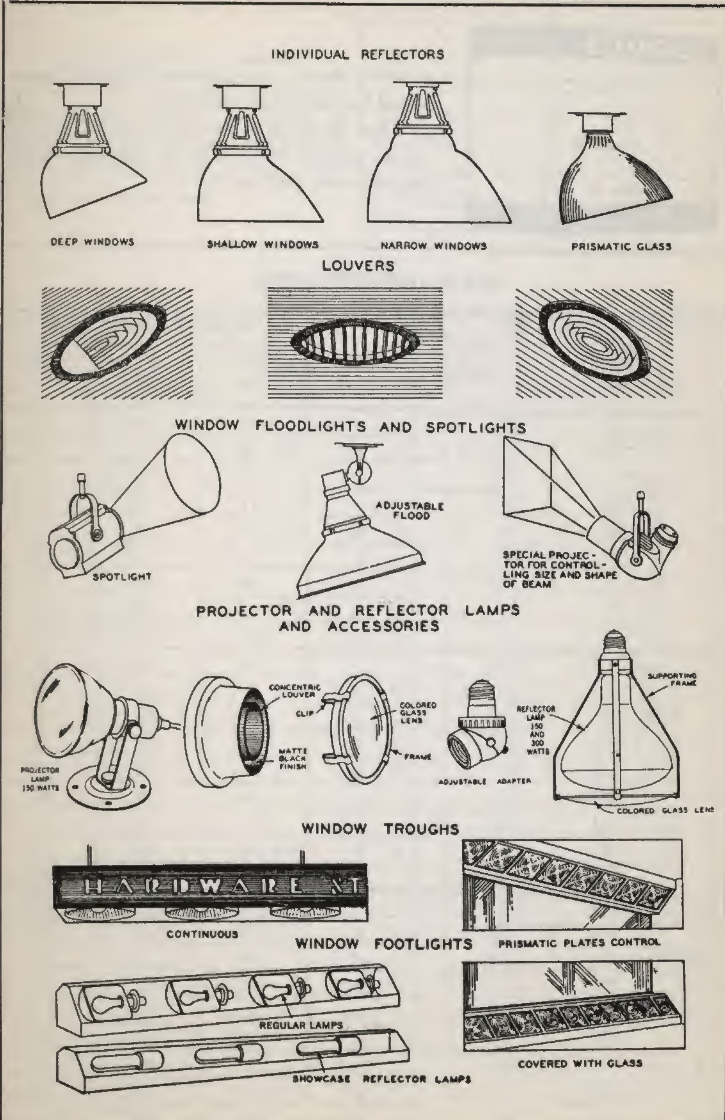
5. **Color**—Colored backgrounds, colored merchandise, colored lighting all have a place in window design. Colored lighting is the most flexible color medium at the display man's command. It can be used to create atmosphere, to improve the appearance of merchandise, and to compel attention through novelty and motion. The lighting, however, must not be so attractive that it draws attention away from rather than *to the merchandise;* it must not distort the true colors of the merchandise in the interest of dramatic effect. "Black light" designs, moving scenic lighting effects (waves, floating clouds, etc.) are only possible when surrounding lighting is of low level approaching actual darkness.

Show Window Lighting

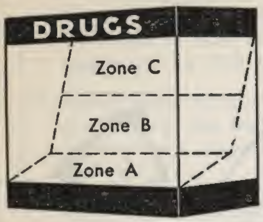
The selection of the proper type of window lighting is determined by the height and depth of the window and also of the display. The merchandise on display must receive the greatest amount of light, hence reflectors which direct the light rays to the display areas with sufficient spill light on the background to remove shadows and give a bright over all appearance to the windows are required. Super-imposed upon this general illumination, spotlighting is recommended to give emphasis and color. Narrow windows will require more concentrating type reflectors or special prismatic control lenses in order to confine the light to the display areas more efficiently.

Typical show window lighting equipment and suggested methods of installation are given in the following sketches:

TYPICAL SHOW WINDOW LIGHTING EQUIPMENT



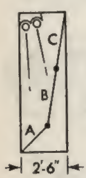
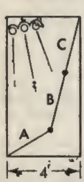
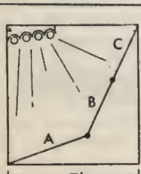
SHOW WINDOW



Values shown in the fluorescent table were determined for the 40-watt White lamp.

Where the length of the window permits the use of the 100-watt White lamp the footcandle values should be multiplied by 1.5.

FLUORESCENT

Window Depth (All 7' high)	No. of Rows	Zone	LENGTH OF WINDOW		
			4'	8'	12'
			FOOTCANDLES		
Narrow	2	A	31	40	45
		B	24	28	33
		C	45	55	63
	3	A	41	51	58
		B	27	33	38
		C	78	95	108
	4	A	56	68	78
		B	38	47	54
		C	110	180	198
Medium	2	A	34	42	47
		B	26	31	36
		C	27	33	38
	3	A	47	58	66
		B	38	48	54
		C	48	59	67
	4	A	62	75	85
		B	51	63	71
		C	66	81	92
Wide	2	A	33	39	45
		B	20	24	27
		C	14	18	19
	3	A	47	57	65
		B	32	38	44
		C	22	27	30
	4	A	60	74	84
		B	44	54	60
		C	29	35	41

DESIGN DATA

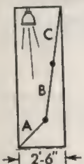
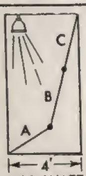
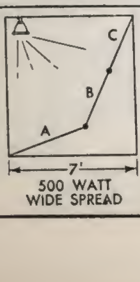
Multiplying Factors for Louvers

All footcandle values have been calculated for fixtures without louvers. If louvers are used the values in the tables should be multiplied by the corresponding "louver factor" to obtain the correct level.

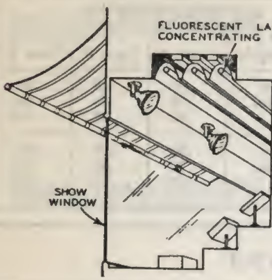
LOUVER FACTORS

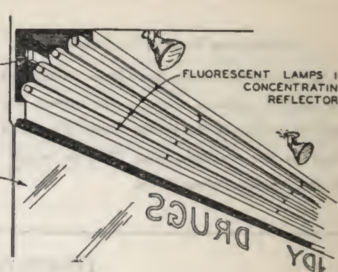
Window Depth		Zone A	Zone B	Zone C
Fluor.	Narrow	.90	.85	.88
	Medium	.91	.86	.85
	Wide	.92	.91	.79
Incan.	Narrow	.80	.70	.58
	Medium	.70	.69	.55
	Wide	.69	.56	.40

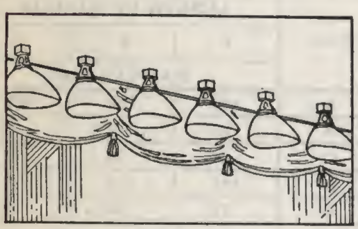
INCANDESCENT

Window Depth (All 7' high)	Lamp Spacing	Zone	LENGTH OF WINDOW 4'	8'	12'
			FOOTCANDLES		
Narrow	12"	A	188	200	200
		B	64	72	72
		C	70	78	78
	16"	A	145	156	156
		B	51	54	54
		C	54	58	58
150 WATT CONCENTRATING	20"	A	114	130	130
		B	39	43	43
		C	43	46	46
Medium	12"	A	179	213	225
		B	118	140	147
		C	66	79	83
	16"	A	135	157	168
		B	88	105	111
		C	50	58	62
200 WATT SEMI-CONCENTRATING	20"	A	112	124	135
		B	74	81	89
		C	41	46	50
Wide	12"	A	318	384	437
		B	226	272	302
		C	139	168	184
	16"	A	234	298	320
		B	168	210	224
		C	101	129	139
500 WATT WIDE SPREAD	20"	A	192	234	256
		B	136	166	182
		C	83	101	111

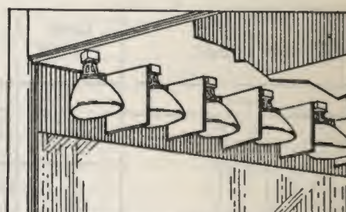
SUGGESTED METHODS OF INSTALLING AND CONCEALING SHOW WINDOW REFLECTORS



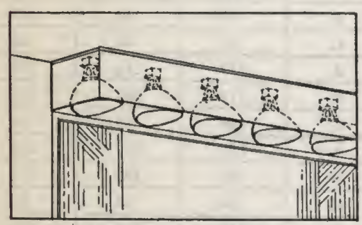




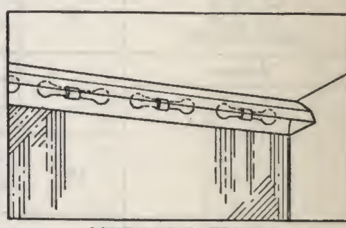
CONCEALED BY VALANCE



VERTICAL LOUVERS BETWEEN

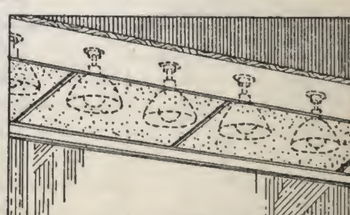


SPECIAL BOX VALANCE

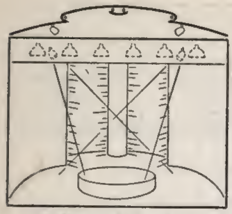


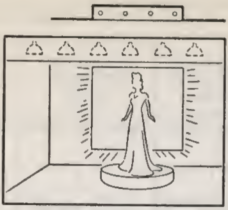
CONTINUOUS TROUGH

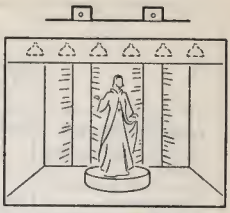
RECESSED
WITH LOUVERS WITH PLATES



ALL GLASS CEILING
WITH REFLECTORS ABOVE


Vertical Coves


Shadow Box for Changing Color Effects

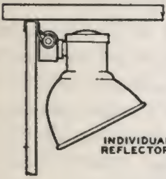

Luminous Pilasters

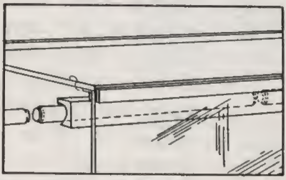
Showcase Lighting

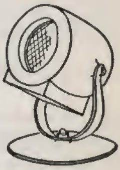
Showcases are miniature show windows, and their lighting should be treated as such. To the general illumination from lamps in small reflectors at the front upper edge, should be added high lighting from small spotlights connected to convenient outlets inside and at the back of the case. Four times the level of the general store illumination should be provided. When the merchandise on display is dark, even a higher ratio is desirable.

Inconspicuous continuous trough type reflectors are available for either the T-bulb filament lamp, the lumiline lamp, the fluorescent lamp, or the showcase reflector lamp. When individual reflectors are used, 25 watt lamps on 12″ to 18″ centers are required. Design procedures and tables for showcase lighting are given in Chapter Six.

SHOWCASE REFLECTORS

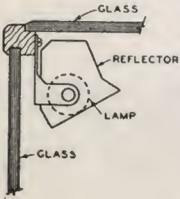

INDIVIDUAL REFLECTORS

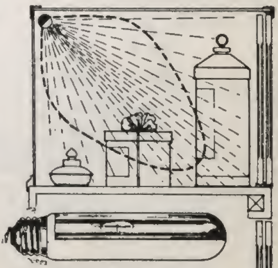

TROUGHS


MINIATURE SPOTS FOR HIGHLIGHTING DISPLAYS

SHOWCASE REFLECTOR LAMPS

FLUORESCENT LAMPS




TYPICAL DISTRIBUTION OF LIGHT FROM A SHOWCASE REFLECTOR LAMP

	SHOWCASES							
	INCANDESCENT LAMPS WITH REFLECTOR		REFLECTOR SHOWCASE LAMPS		LUMILINE LAMPS		FLUORESCENT LAMPS	
	Spacing	Watts	Spacing	Watts	Spacing	Watts	Spacing	Watts
LARGE CITIES								
Brightly Lighted Districts	12″–18″	40–60	12″	40	18″	60*		
Secondary Business Locations	12″–18″	40–60	12″	25	18″	60*		
Neighborhood Stores	12″–18″	25	12″–18″	25	18″	30	18″ or 36″ Lamps ** mounted end to end in continuous rows.	
MEDIUM CITIES								
Brightly Lighted Districts	12″–18″	40–60	12″	40	18″	60*		
Neighborhood Stores	12″–18″	25	18″	25	18″	30		
SMALL CITIES AND TOWNS	12″–18″	25–40	18″	25	18″	30		

* 12″—40 watt Lumiline Lamps mounted end to end will produce the same level of illumination as 18″—60 watt lamps, and may be substituted in the above tables.

** The 9″—6 watt and the 12″—8 watt fluorescent lamps may be used in small narrow cases where space is limited.

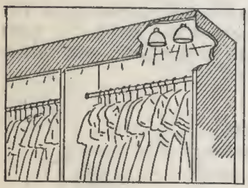


Fig. 1

Wall Case Lighting

These cases may be illuminated (1) by small individual reflectors similar to those used in show windows, employing 60 watt lamps on 18″ centers; (2) by the showcase reflector lamps if the displays are less than 4 ft. from the lamps; (3) by continuous rows of fluorescent lamps; (4) by totally luminous ceilings; or (5) by the use of prismatic glass plates recessed in the ceiling. (See sketches). The size of the case and the height of the display will determine which method is the most suitable. For selling effectiveness, at least four times more light is required in the case than the general store illumination.

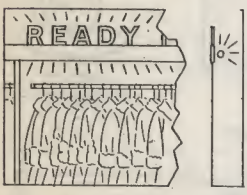


Fig. 2

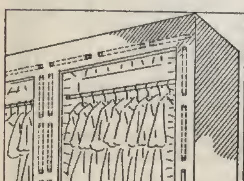


Fig. 3

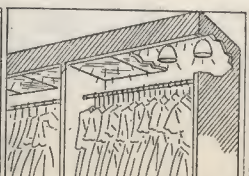


Fig. 4

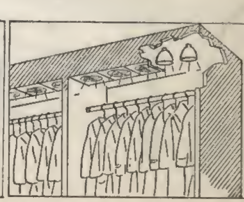
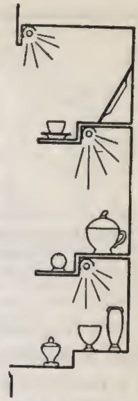


Fig. 5

WALL CASES AND DISPLAY SHELVES ***							
Incandescent Lamps with Reflector		Reflector Showcase Lamps		Lumiline Lamps		Fluorescent Lamps	
Spacing	Watts	Spacing	Watts	Spacing	Watts	Spacing	Watts
12″	100	8″	40				
12″	60	8″	40	12″ or 18″ Lamps mounted end to end in continuous rows.	40 or 60	18″, 24″, 36″ or 48″ Lamps mounted end to end in continuous rows.	
12″	40	12″	40				
12″	60	8″	40				
12″	40	12″	40				
12″	25–40	12″	25–40				

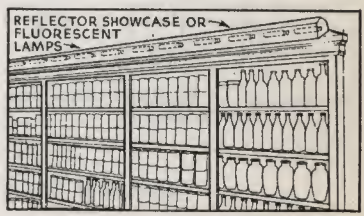
*** Data given apply only when lighting equipment is located at top of case and not for an individual lighting unit at each shelf. In the latter case Lumiline, Showcase Reflector Lamps, and Fluorescent Lamps should be used in accordance with data given in table for Show Cases.



Lighting from under shelves

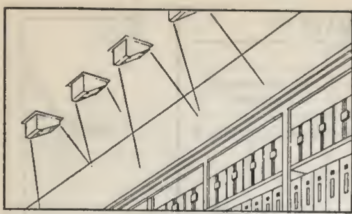
Display Shelf Lighting

The level of illumination on the vertical should vary no more than five to one from the topmost shelf to the lowest one at the floor. This requirement is usually met (1) by a continuous trough providing 60 to 100 watts per running foot for incandescent lamps, or a continuous row of fluorescent lamps; (2) by small individual reflectors on 8″ to 12″ arms so spaced that the above wattage per running foot is provided; (3) by specially designed prismatic lighting fixtures attached to the ceiling to direct a beam of light at an angle on the shelves; or (4) by special lighting arrangements attached to each individual shelf, such as "edge" lighting or luminous background lighting.

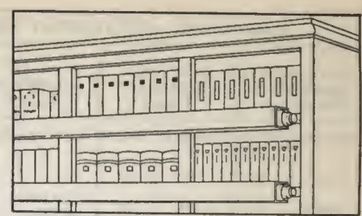


Reflectors should so Direct the Light that the Illumination on the Lower Shelves Varies Little from the Level of the Top.

Individual Reflectors so Spaced that 40—100 Watts per Foot is Provided.



150—200 Watt Fixtures Equipped with Prismatic Lenses



Lumiline or Fluorescent Lamps

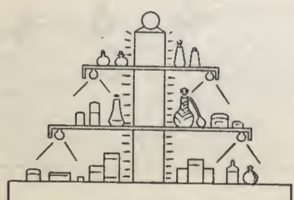
It is frequently possible to design the shelf lighting to provide upward light as a background for a silhouette sign or to conceal the lamps back of a luminous panel on which a sign is inscribed.

Combination of Luminous Sign and Shelf Lighting

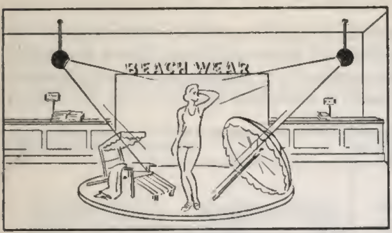
Combination of Silhouette Sign and Shelf Lighting

Floor and Table Display Lighting

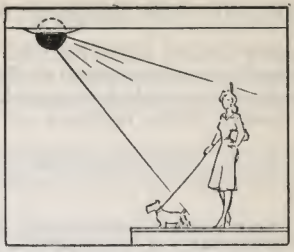
Displays of smaller objects on tables or counters, or larger displays such as wax figures placed directly on the floor with or without accompanying backgrounds should be lighted in such a manner that glare and deep concealing shadows are eliminated in so far as possible. Glare control depends upon the location of the equipment with respect to the normal viewing position and the proper louvering and shielding of the source of light. Deep shadows are eliminated by directing light on the display from two locations such that the rays from one source will illuminate the shadows cast by the other source. Special equipment designed for good appearance and easy concealment is available to illuminate displays of this type from the ceiling or side walls at a distance from the displays. Frequently, the light sources can be attached to the displays, thereby simplifying both the shadow and the glare problems.



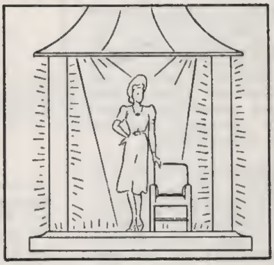
Free Standing Counter Display



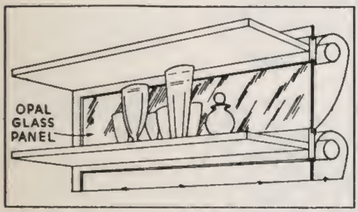
Floor Display Illuminated by Special Spotlight Fixtures Designed to Direct the Light on the Display with Little Spill to Prevent Glare. Harsh Shadows are Eliminated by the Light Coming from Two Directions.



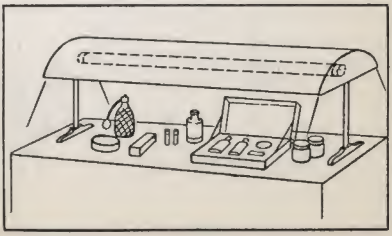
Semi-Recessed Spotlight in Ceiling Illuminates Display Against the Wall Without Glare to Spectators.



A Wall Canopy Conceals the Spotlighting of this Display. Footlights and Decorative Background Lighting Add Attraction Value.



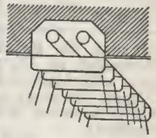
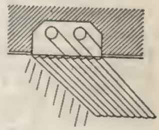
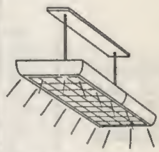
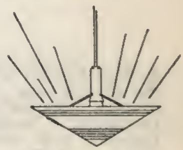
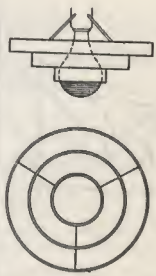
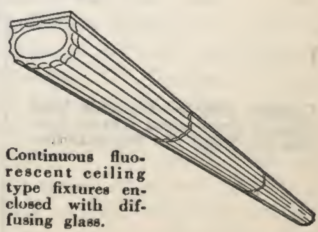
Luminous Background Provided by Continuous Row of Fluorescent Lamps.



Counter Display Lighting from Special Fluorescent Fixture Suitable for Small Flat Merchandise.

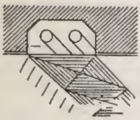
LIGHTING FOR OFFICES AND DRAFTING ROOMS

Seeing tasks in offices and drafting rooms range from those requiring severe discrimination of fine detail for long periods of time, to those where seeing is casual and frequently interrupted. Office workers are confined to no particular age group. Office buildings are frequently hemmed in by other buildings

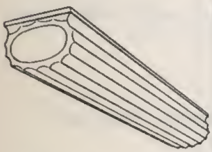
	SEEING TASK	LIGHTING SUGGESTIONS	TYPICAL LIGHTING
GENERAL OFFICE AND PRIVATE OFFICES	Range from difficult—poor contrast, fine detail long periods of time, — to ordinary, such as general correspondence filing.	Direct-indirect, semi-indirect, indirect, or shielded troffers are standard recommendations. Symmetrical spacing where possible provides high level well diffused, glareless general illumination. (See recommended levels for offices, Chapter Five), Ceiling mounted, recessed or pendant style equipment may be used, depending upon ceiling height of the room. Architectural lighting and more decorative fixtures are frequently required for private offices. Supplementary lighting on business machines and desks should be adjustable, well shielded, and properly positioned with reference to the work area, to eliminate reflected glare. Designs that provide upward lighting in addition to light on the working area are preferred.	 Troffer with louvers.  Troffer with fluted glass cover.  Direct - indirect fluorescent pendant fixture with louvers or diffusing glass cover.  Indirect incandescent.  Louvered silvered bowl fixture.  Continuous fluorescent ceiling type fixtures enclosed with diffusing glass.

which exclude daylight as a dependable means of illumination. Desk arrangements must be flexible. Eyesight conservation is necessary for full employee efficiency and speed of work. All of these factors must be considered fully in designing office and drafting room lighting to produce the best seeing conditions.

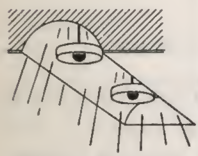
EQUIPMENT



Troffer with prismatic plates.



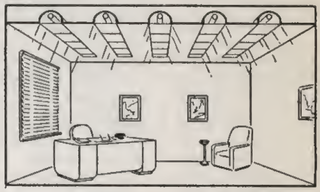
Ceiling type fluorescent fixture (1, 2, or 3 lamps).



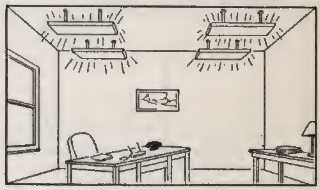
Precast plaster coffers with louvered silvered bowl lamps.

TYPICAL INSTALLATIONS

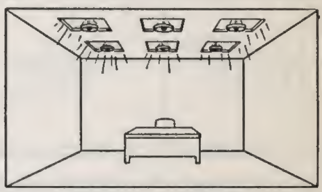
Fluorescent troffers with louvers spaced 3 ft. apart—average ft-c in service: 50.



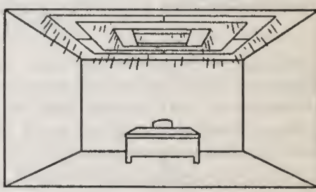
Direct-indirect fluorescent, spacing 6′ x 8′. Average ft-c 50.



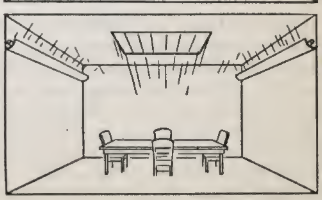
Precast plaster troffers with 500-watt silvered bowl lamps. Average ft-c 30.

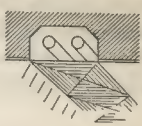
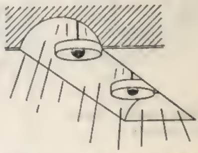


Fluorescent fixtures arranged in rectangular pattern. With 100-watt fluorescent lamps. Average ft-c 60.



Cove lighting combined with special down lighting at desk. Prismatic plates control direction of light rays.

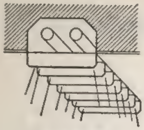
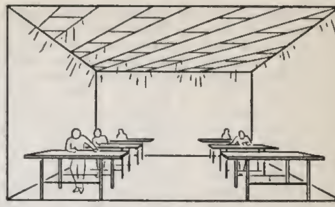
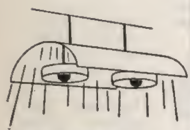
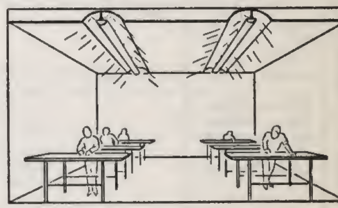
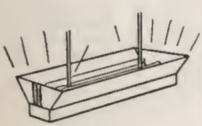
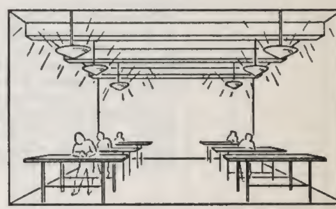


	SEEING TASK	LIGHTING SUGGESTIONS	TYPICAL LIGHTING
DRAFTING ROOMS	Accurate discrimination of fine detail for prolonged periods of time is common in these rooms. Contrast between work and background is likely to be poor. Reflected glare from paper and instruments is a constant seeing hazard. Shadows from instruments and hands interfere with work.	Low brightness large area light sources, capable of delivering 50 ft-c or above on the work plane, are required. Indirect lighting, direct lighting from luminous ceilings, continuous row semi-indirect lighting properly positioned with reference to the drafting boards, or shielded troffer direct lighting properly positioned are accepted practice in drafting rooms. Boards in a vertical position reduce the glare and shadow hazards, and fixtures of small luminous area may be used provided the high levels required for this work are maintained.	**TROFFERS**  Shielding glass of prismatic plates. **LARGE AREA SOURCES**  Rectangular coffers with shielded silvered bowl lamps. **INDIRECT FIXTURES**  Indirect Semi-indirect Luminaires

CLASSROOM, LABORATORY, AND VOCATIONAL TRAINING ROOM LIGHTING

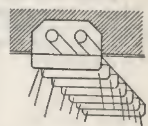
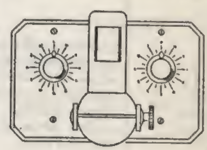
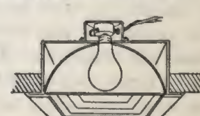
Eyesight conservation and improved scholarship are the primary objectives in all school lighting design. Young eyes in the formative stages are subjected to severe visual tasks over relatively long periods of time in the schoolroom. High level, glareless, well diffused, natural and artificial lighting are essential if the life-long handicap of bad vision is not to occur in a high percentage of school children.

Daylighting in Schools—Classrooms should be so constructed that windows are on one side only, with a total window area never less than $\frac{1}{10}$ of the floor area—$\frac{1}{4}$ would be a better ratio. They should extend to within 6″ of the ceiling, and never beyond the front row of desks. Translucent shades (two per window) fastened with both rollers at the middle of the window in such a manner that they may be raised and lowered from this location, or venetian blinds should be installed to give proper control of the light entering the room. Desks should be so arranged that natural lighting comes from the side and slightly back of the pupils. The best exposure for class rooms is northeast or northwest.

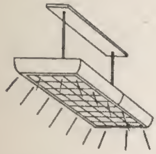
EQUIPMENT	TYPICAL INSTALLATIONS
 Louvered	**Fluorescent troffers arranged diagonally with respect to horizontal drafting boards.** 
 Low brightness large area fixtures	**Large area low brightness fixtures suspended or recessed in ceiling directly over drawing boards.** 
 Indirect fluorescent	**Indirect lighting from suspended fixtures provides large low brightness area above boards. Deep beams reduce ceiling area in direct line of view.** 

Artificial Lighting in Schools—Artificial lighting of classrooms and other study rooms must supplement daylight so that high level, well diffused, glareless illumination is available at any hour of the day, any month of the year. While this need for artificial illumination has been generally recognized, it has only been recently realized that artificia lighting should be used in some sections of the room even on normally bright days due to the rapid decrease of daylight across the classroom away from the windows. Pupils sitting close to the windows receive as much as 20 times more light than pupils at the far side of the room away from the windows unless artificial lighting is employed.

It is no longer sufficient to provide illumination for day classes only since the modern educational system includes extension classes and community gatherings at night as well. The lighting installation therefore should be designed to provide good illumination to meet both day and night conditions. The following table will serve as a guide in planning school lighting; for more detailed instructions, refer to the American Standard Practice of School Lighting—a publication of the Illuminating Engineering Society.

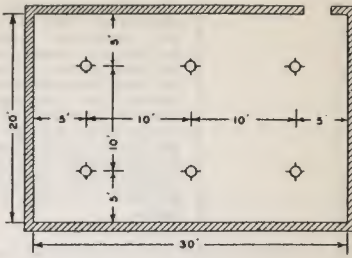
	SEEING TASK	LTG. SUGGESTIONS	TYPICAL LIGHTING
CLASSROOM DESKS AND BLACKBOARDS	Discrimination of fine details for long periods of close application. Near and distant vision involved. Defective eyesight prevalent in higher grades. Type size and contrast vary from good to very poor in school text books. Reflected glare from books, desks, and blackboards a seeing hazard.	*General Illumination* — High level (see Chapter Five), well diffused, glareless illumination from low brightness fixtures is required. Where filament lamps are employed, semi-indirect or indirect luminaires are recommended. With fluorescent lamps any of the luminaire types may be used, provided the bare lamps are shielded from normal viewing angles.	**GENERAL ILLUMINATION**  **Low-brightness diffusing glass enclosed fluorescent fixtures for individual, multiple or continuous mounting.**  **Luminous bowl indirect for filament lamps.**  **Louvered fluorescent troffer for direct lighting.**
		Photo Cell Control—Photo cell control of the lighting is desirable, especially of the row of fixtures farthest from the windows. Photo cells are usually located on the end wall as far as possible from the windows. One control for several rooms with the same exposure is possible.	**PHOTO CELL CONTROLS**  **Control mechanism and cell as a unit.**
		Blackboards — Auxiliary lighting of blackboards is desirable in sight saving class rooms or where general lighting does not exceed minimum recommended levels. Prismatic lens control to confine the light to the blackboard and to provide high vertical illumination is recommended. For small blackboards or charts, a reflector or projector floodlight lamp with suitable bracket may be attached to the ceiling in such a way that the angle of the beam prevents excessive glare in the eyes of the teacher or pupil at the board.	**BLACKBOARD LIGHTING**  **Prismatic lens fixture recessed in the ceiling.**

EQUIPMENT	TYPICAL INSTALLATIONS



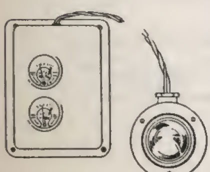
Louvered or diffusing glass shielded fluorescent direct-indirect fixture.

Typical lighting layout for average classroom.



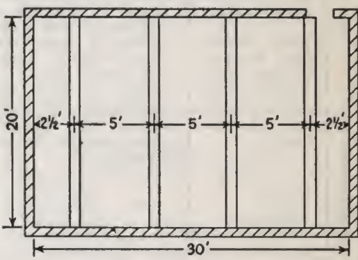
INDIRECT LIGHTING DATA

Size of Lamp	Approx. Ft-c
500 watts	15
750 watts	25
1000 watts	35



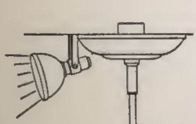
Control mechanism and cell separated.

Typical layout for fluorescent louvered troffers recessed or flush with the ceiling.



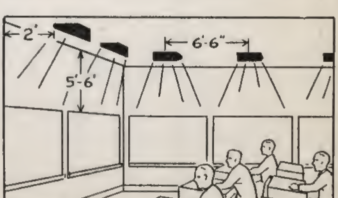
LIGHTING DATA FOR 40-WATT WHITE FLUORESCENT LAMPS

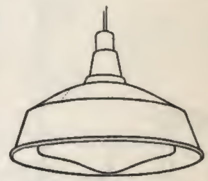
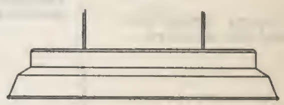
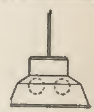
Spacing of Troffers (on centers)	Approx. Ft-c (in service)
7′	30
5′	40
3′	60

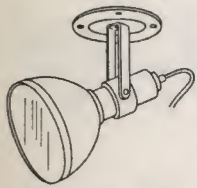
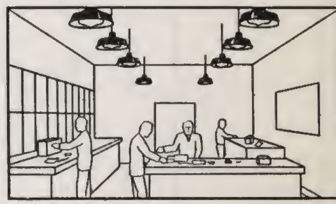
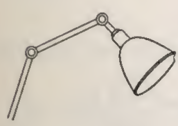


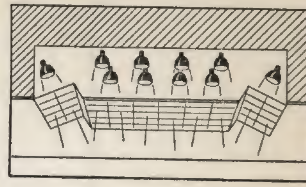
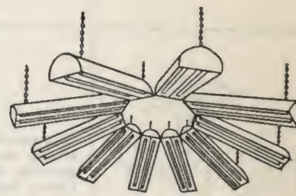
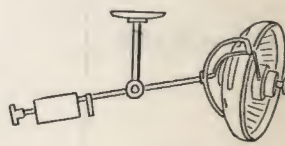
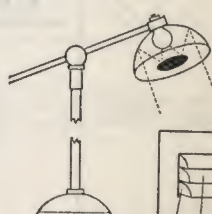
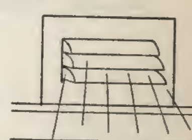
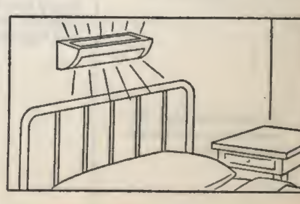
Reflector or projector lamp attached to fixture canopy by special bracket.

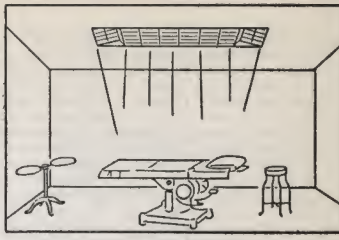
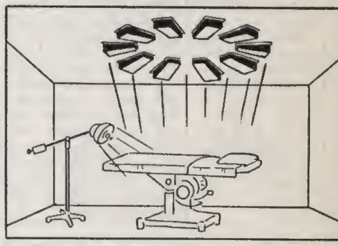
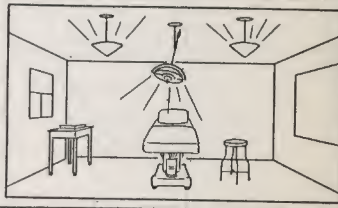
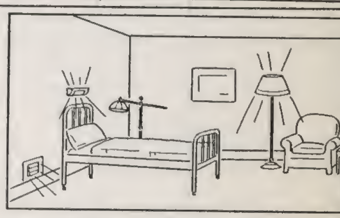
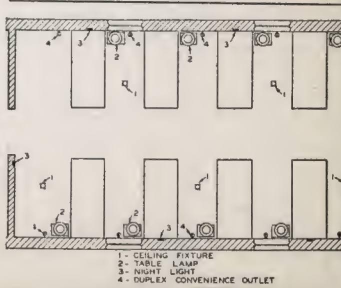
Typical lighting layout for **blackboards**, using prismatic lens fixtures.



	SEEING TASK	LIGHTING SUGGESTIONS	TYPICAL LIGHTING
LABORATORIES		The seeing requirements parallel so closely those in the classroom, general lighting recommendations for laboratories are similar. Special supplementary lighting for microscopic work and reading delicate instruments should be provided by small portable stands and reflectors. Convenience outlets should be provided at all work tables.	
VOCATIONAL TRAINING	Similar to those in industrial shop and wood working factories. Safety is a factor as well as eyesight conservation. Task varies from discriminating fine detail for long periods to casual observation.	*General Illumination*—Refer to Chapter Nine, "Industrial Lighting", for design details. Location and spacing of fixtures to eliminate shadows and reflected as well as direct glare is required. Supplementary lighting for machines or work benches should be provided when the seeing task demands prolonged observation of critical detail. Illumination levels should correspond to those recommended for industrial interiors with similar machines and work requirements.	 Glassteel Diffuser  Industrial fluorescent RLM fixture for 40- and 100-watt fluorescent lamps. 

EQUIPMENT	TYPICAL INSTALLATIONS
 Industrial Spotlight	Glassteel diffusers spaced to provide well diffused, high level lighting. 
 Adjustable arm supplementary fixture.	Continuous rows of RLM fluorescent fixtures. 
 Adjustable arm fluorescent supplementary fixture.	Supplementary lighting plus general lighting. 

	SEEING TASK	LTG. SUGGESTIONS	TYPICAL LIGHTING
OPERATING ROOM	Very critical and exacting. Time is a big factor. Contrasts are generally poor, and glare is a constant hazard. Shadows interfere greatly in the seeing process.	High level (2000 foot-candles or more), shadowless illumination on the operating table combined with excellent general lighting (50 ft-c or more) throughout the operating room is required. Portable supplementary spotlighting that can be easily adjusted should also be supplied for deep cavity illumination. An emergency lighting system operated from an independent source of power supply is essential.	  
WARDS AND PRIVATE ROOMS	Critical for short periods during doctor's examination. Weakened condition of the eyes complicates patient's seeing tasks. Reading and writing to a moderate degree is customary.	These rooms should be provided with (1) general well diffused illumination from luminous bowl indirect fixtures; (2) localized bed lights for patient's convenience; (3) portable reading lamps for nurses and patient's convalescent period; (4) portable examination lamps for doctor's use; and (5) night light under bed or in baseboard of the room. Direct—indirect wall fixtures at the head of the bed are preferred to ceiling units. Ceiling brightness must be kept low since it is in direct line of view of the patient. In wards where general lighting from indirect fixtures is customary, the best spacing arrangement is between beds, about half the bed length from the wall.	  

EQUIPMENT	TYPICAL INSTALLATIONS	
Built-in prismatic lens operating room fixture.	**Luminous Ceiling Composed of Lens Plates** Concentrates the light from many directions on the operating table.	
Fluorescent fixture arrangement for operating rooms.	**Individual Lens Lights on Ceiling** Light from many directions eliminates shadows on working area.	
Suspended operating room fixture with special reflector.	**Special Adjustable Fixture** The reflector in this unit is designed to direct light on the table from various parts of its surface, thereby reducing shadows in the work area.	
Adjustable Examination Light Parabolic reflector. Direct rays shielded from view. **Night Light** Louvered baseboard light recessed in the wall.	Lighting equipment for private rooms.	
Special Private Room and Ward Lighting Fixture Provides indirect light for general illumination and direct light for reading, writing, etc.	**Floor Plan** Indirect lighting layout for wards.	

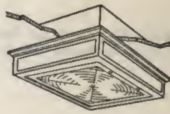
LIGHTING FOR BANKS

	SEEING TASK	LTG. SUGGESTIONS
MAIN LOBBY TELLERS' CAGES PUBLIC WRITING TABLES	If lobby area is used only for passage and casual seeing, the visual task is not critical or prolonged; but frequently the lobby area and the tellers' cages merge and the general illumination serves both. The visual task in the tellers' cages and bookkeeping areas is both critical and prolonged, requiring high illuminations for efficient eye work.	The lighting design must create atmosphere and conform to the architectural decoration of the room. Direct—indirect type chandeliers, coves combined with downlights, luminous architectural elements on ceiling or walls, or real or false sky lights illuminated from above—all offer decorative possibilities combined with good lighting design. Illumination levels must be high if the general illumination is used both for the lobby and bookkeeping areas, as is frequently the case. Supplementary lighting for teller's counters and public writing desks is required unless general illumination levels are sufficient at these locations without glare or deep shadows.

TYPICAL LIGHTING

DOWN LIGHTS

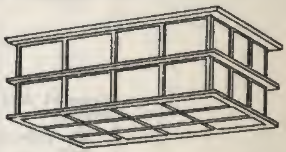
Louvered Type



Prismatic Lens Type

COVES—LUMINOUS ARCHITECTURAL ELEMENTS
(See Chapter Ten)

DECORATIVE LUMINAIRES



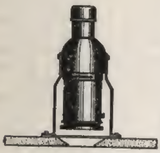
Fixture of luminous white glass side panels and prismatic lens plates on bottom.

TELLERS' CAGES

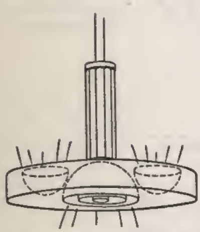
PUBLIC WRITING TABLES

EQUIPMENT	TYPICAL INSTALLATIONS

EQUIPMENT



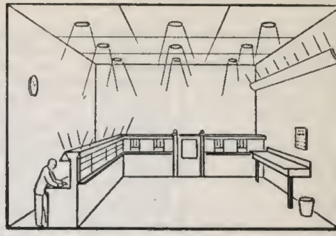
Pin-hole Type



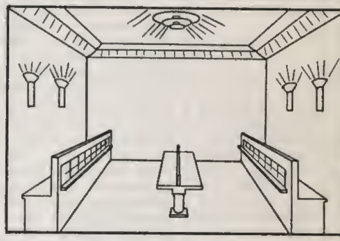
Fixture combining direct and indirect lighting and decorated with luminous glass elements.

TYPICAL INSTALLATIONS

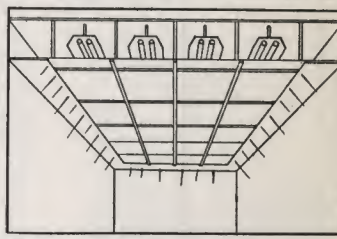
Downlights from ceiling coffers and indirect lighting from top of tellers' cages or wall coves.



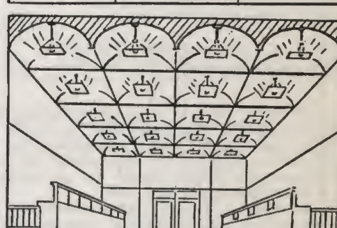
Luminous panels or decorative indirect fixtures on wall or ceiling.



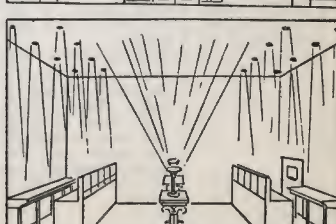
Illuminated sky-lights—individual reflectors or trough sections.

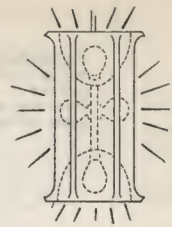
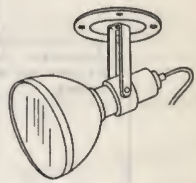
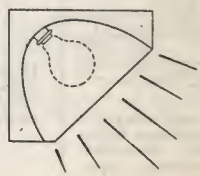
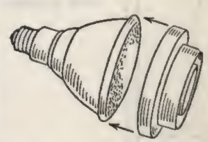


Ceiling of precast plaster coffers and silvered bowl lamps with louvers.

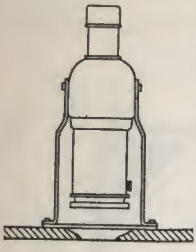


Pin-hole downlights over tellers' cages and bookkeeping area with indirect lighting from pedestals incorporated in writing tables.

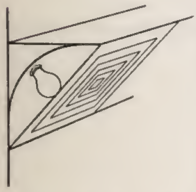


	SEEING TASK	LTG. SUGGESTIONS	TYPICAL LIGHTING
CHURCH AUDITORIUM	Rarely prolonged, but involves reading fine print during part of the service.	Two levels of illumination are desirable—one for the reading of the service, another during the delivery of the sermon. All lighting must be well shielded and diffused in the interest of eye comfort. It must be designed to produce a mood of restfulness and quiet, while concentrating attention on the altar, pulpit, sanctuary, or choir as the service requires. Decorative lanterns of the direct—indirect lighting type, recessed "pin hole" lights in tall vaulted ceilings, recessed prismatic plates, architectural coves, and floodlighting of side walls or ceiling are methods most frequently employed in modern practice. Architectural style of the church should be considered.	 Luminous lantern type fixture for direct—indirect lighting. Down lighting through louvered or diffusing glass cover used only during reading of the service.
ALTAR	A high level of illumination is required to direct audience interest and attention to the details of the altar ritual.		 Reflector and projector lamps for altar floodlighting.  Continuous trough for filament or fluorescent lamps for altar highlighting.
PULPIT	Reading sermon notes at a rapid rate and with the eyes at a distance from the lectern is a severe eye task. High level illumination is required.	To attract attention to the pulpit and to provide eyesight protection, the pulpit area should be highlighted for the period it is in use. Inconspicuous lectern type reading lamps provide illumination for reading but do not high light the speaker. Well concealed (back of beams or similar architectural features) spot lights directed from opposite sides of the church will provide both lighting for seeing and for the speaker and are preferred.	PULPIT LIGHTING UNITS  Reflector or projector spot lamps (louvered). LECTERN LIGHTING UNITS 

EQUIPMENT



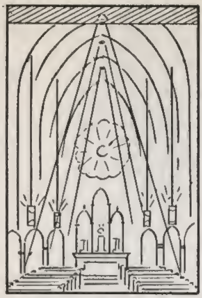
"Pin-hole" down light for high ceilings.



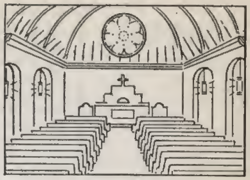
Light troughs with prismatic lens or diffusing glass plates to light altars, or concealed back of beams to illuminate the church auditorium.

Lens Spotlight

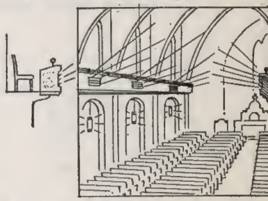
TYPICAL INSTALLATIONS



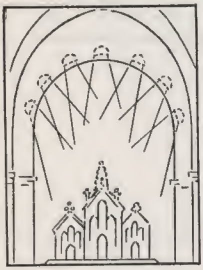
"Pin-hole" down lighting plus decorative fixtures.



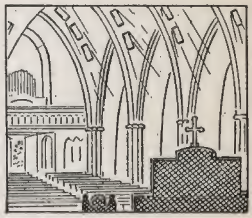
Luminous architectural recessed fixture and cove lighting.



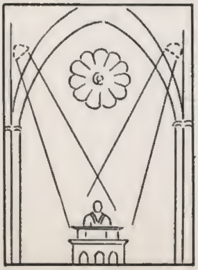
Recessed floodlights directed on opposite walls indirectly lighting auditorium.



"High lighting" the altar from concealed floodlights to give emphasis and direct attention.



Special light troughs concealed back of beams and facing the altar.

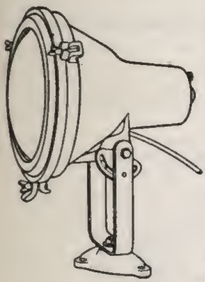
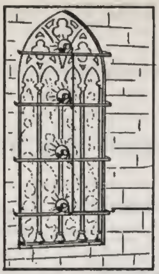
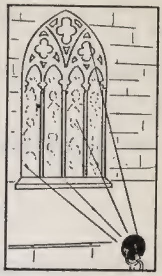


Spotlights concealed behind arches or beams light this pulpit from two directions.

Indirect lighting from a cove at the edge of the canopy over the pulpit plus a direct light for the lectern.

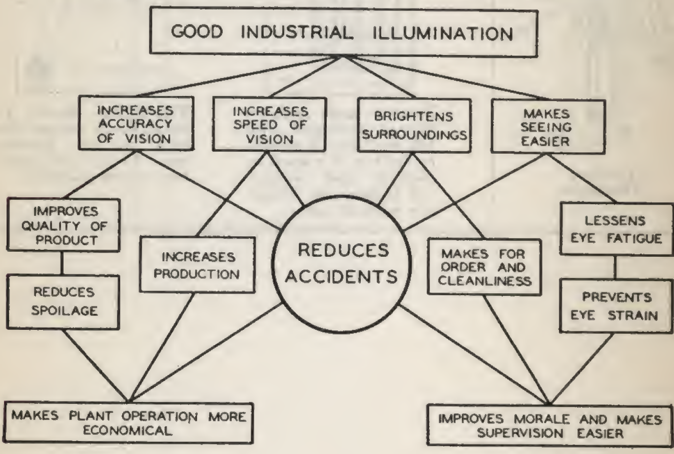
LIGHTING FOR CHURCHES (Cont.)

	SEEING TASK	LTG. SUGGESTIONS	TYPICAL LIGHTING
STAINED GLASS WINDOWS	Decoration and atmosphere.	The darkness of stained glass windows is relieved at night by lighting from the exterior. Angle type reflectors fastened to the building or floodlighting from the ground or standards is general practice. Concealment of all lighting equipment should be considered in the interest of the exterior appearance of the church.	STAINED GLASS WINDOW  Angle Reflector

EQUIPMENT	TYPICAL INSTALLATIONS	
LIGHTING	EXTERIOR WINDOW LIGHTING	
 Outdoor Floodlight	 Three or more angle reflectors equipped with 150 watt lamps located at the top of a small or medium size window will increase its decorative value at night.	 Floodlights should be louvered to confine the rays to the window area. Conceal by shrubbery where possible.

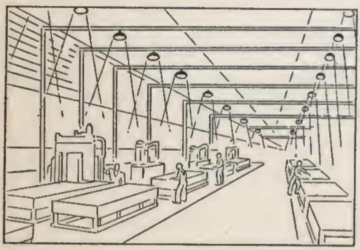
CHAPTER NINE
INDUSTRIAL LIGHTING

BENEFITS OF GOOD INDUSTRIAL LIGHTING



TYPES OF MODERN INDUSTRIAL LIGHTING

General Lighting



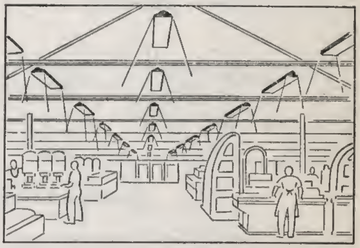
1. High Bay Narrow Interior

Luminaires which concentrate the light in a relatively narrow beam are desirable for this application in order to efficiently provide the necessary illumination at the working plane. Equipment with wide distribution would direct much of its light to the side walls and window area where it would be very largely absorbed.

Incandescent or mercury sources are used for this application either alone or in combination, the type used being determined in part by the character of the work performed in the area, the footcandle level desired, and the facilities for mounting and servicing. Where color discrimination

is not necessary, mercury lamps may be used with the advantage of long life and high efficiency. The use of the higher-wattage lamps, such as the 3000-watt mercury lamp, in direct-lighting equipment should be considered only where the mounting height is 40 feet or more and the material being worked on is of a non-specular character. When color correction is necessary in the use of mercury equipment, at least 15% of the lumens should be produced by incandescent lamps in order to provide an appreciable color improvement. There is little economical advantage in a combination system where more than 60% of the lumens are produced by incandescent lamps.

2. *High Bay Wide Interior*



Equipment with a wide distribution may be used effectively in areas of this nature to provide a greater overlapping of light beams with a resultant reduction in shadow intensity and with higher vertical surface illumination. In rows of luminaires near the building walls, concentrating equipment should be used to minimize the loss through wall and window absorption.

In addition to incandescent and mercury vapor lamps, which are recommended for narrow high bay interiors, fluorescent lamps are suitable for use in wide high bay areas where lower-brightness sources are desired. They are particularly necessary where specular materials such as airplane sections are being fabricated. Where proper facilities for servicing can be employed, such as cranes or extension platforms, mounting heights up to 50 feet are possible providing the width of the room is at least five times the mounting height. The use of the 100-watt fluorescent lamp in RLM luminaires may have an advantage from a maintenance standpoint due to the fact that fewer lamps and luminaires will be necessary to provide the required level of illumination.

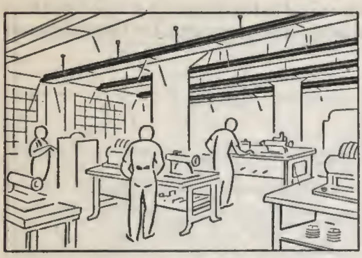
3. *Low Mounting*

The lighting equipment selected to produce uniform illumination from low mounting heights is usually of the wide-angle distribution type. Luminaires which do not produce a wide distribution must be more closely spaced to avoid spotty lighting.

For low mounting-height incandescent installations, the RLM Standard Dome may be used effectively. Another type of equipment with lower brightness and better diffusion is the Glassteel Diffuser, which may be used with either filament or mercury vapor lamps. Fixtures designed for use with silvered bowl lamps provide another means of reducing the brightness of the light source.

The majority of industrial low mounting installations now being made use fluorescent lamps in RLM luminaires. Fluorescent RLM luminaires

are available in the conventional open type, or with various forms of louvers, with glass covers, and in vapor-proof units. The wide distribution of this type of luminaire, its relatively low brightness, and its comparative coolness make it particularly suitable for the lower mounting heights. Maintained illumination levels of 50 footcandles are readily obtainable with fluorescent luminaires.



A popular practice in industrial lighting is to install fluorescent luminaires in continuous rows. If an original installation in continuous rows is not desired, it may be advisable to space the fixtures in such a way that an additional fixture can later be added between adjacent units to form a continuous line. In this way, illumination levels may be doubled without great additional wiring expense.

Localized General Lighting

Many industrial plants have machinery of such a nature or so located that it lends itself to the positioning of luminaires with specific reference to the working points. Where a uniform intensity of illumination is not necessary throughout the area, such a positioning of lighting equipment permits the obtaining of high levels at the particular work points and at the same time provides sufficient illumination for adjacent areas.

Supplementary Lighting

When the general level does not provide enough illumination for a particular task, supplementary lighting equipment should be employed. This produces the desired levels by concentrating light at the point of work. There are several methods of achieving this result depending on the size of the work area, its location, and the possible location of the lighting equipment.

1. Small Areas

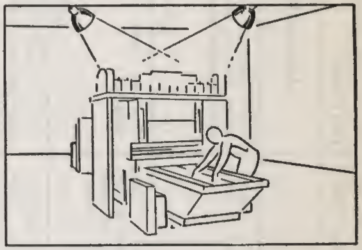
Where areas are small and the lighting equipment can be mounted close to the task, adjustable brackets or fixed channels may be mounted on the machines or benches.

Individual incandescent lamps in small reflectors with adjustable arms supply up to 300 footcandles at distances of approximately ten inches.

Fluorescent lamps with individual reflectors mounted close to the working area will give more than 150 footcandles of high-quality, low-brightness illumination.

2. Larger Areas

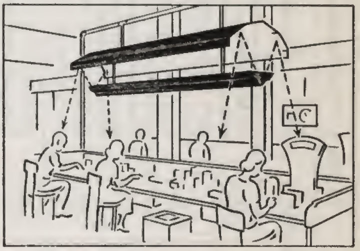
Where the light must be projected on areas which cannot readily be reached by other methods or where reflectors mounted close to the work would interfere with the workman's operation, larger-wattage equipment mounted at a distance must be employed. Special reflectors are manufactured for this purpose. The PAR-38 and R-40 spot and flood lamps requiring no external reflector are particularly suitable for applications of this nature. The units should be located so that the operator does not cast a shadow on the work.



3. Low-Brightness Sources

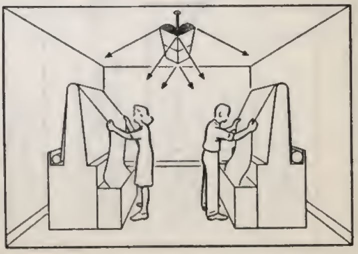
Certain types of work such as typesetting and sheet metal work require a large, low-brightness source for best seeing conditions. Incandescent lamps in a large glass-covered fixture or in a large-area indirect lighting unit would be suitable.

Direct-lighting fluorescent fixtures such as the RLM, if covered with frosted or opal glass, will give high levels of illumination with low source-brightness.

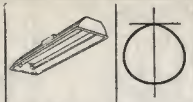
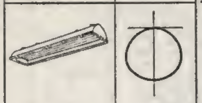
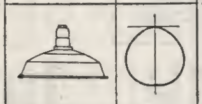
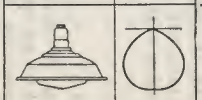
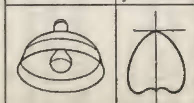
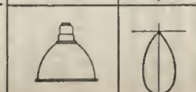


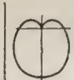
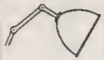
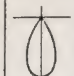
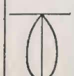
4. Vertical Surfaces

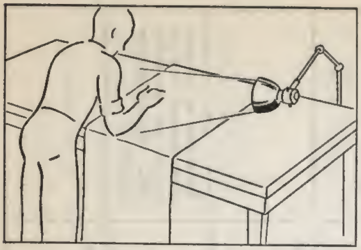
When a high level of vertical illumination is needed on an operation such as an assembly line, fluorescent fixtures with asymmetric light distribution or symmetrical fixtures tilted at an angle can be mounted on each side of the conveyor. Elliptical angle reflectors with incandescent lamps can be used, but precautions must be taken to prevent glare if the operators are forced to look directly into them.



TYPES OF INDUSTRIAL LIGHTING FIXTURES

Application	Luminaire	Description	Lamp Sizes	Remarks
Low Mounting General Lighting Localized General Lighting		RLM Reflector. Porcelain enameled steel. Available with either open or closed ends.	Two 100-watt or two or three 40-watt fluorescent, also Slimline lamps.	Glass - covered and louvered units available.
Low Mounting General Lighting for dusty or other hazardous places.		Porcelain enameled steel. Has dust and vapor-tight hinged cover. Meets Underwriters' requirements for certain hazardous conditions.	Two or three fluorescent lamps.	Explosion-proof units also available.
Low Mounting General Lighting Localized General Lighting		RLM Standard Dome Reflector. Porcelain enameled steel. Wide distribution with cut-off at 72½° from the vertical.	75-watt to 1500-watt general service or white bowl lamps.	Dust-tight cover available with clear or stippled glass.
Low Mounting General Lighting Localized General Lighting		Glassteel Diffuser. Porcelain enameled reflector with opal glass enclosing globe used to obtain softer, better diffused light with a small upward component.	150-watt to 1000-watt general service lamp, 250-watt or 400-watt mercury vapor lamp.	
Low Mounting General Lighting		RLM reflector for use with silvered bowl lamps. Some have aluminum inner reflector	300- or 500-watt silvered bowl lamps.	
High Mounting General Lighting		Aluminum, porcelain enamel, silvered or prismatic glass reflectors. Concentrated, medium or wide distribution.	300-watt to 1500-watt general service. 400-watt mercury vapor, one or two lamps.	Dust-tight covers available.

Low Mounting General Lighting Localized General Lighting			Cast iron hood with threaded vapor-tight clear glass globe. Available with four types of porcelain enamel reflectors including the RLM Dome.	75-watt to 300-watt general service.	
High Mounting General Lighting			Porcelain enameled steel. Minimum mounting height 40′. For use in heavy industrial plants where economics dictate a minimum number of luminaires.	3-Kw A-H9 mercury vapor lamp only.	
Supplementary Lighting. Mount close to working area.			Small deep bowl reflector of porcelain enameled steel.	15-watt to 100-watt general service.	Adjustable mounting arms available.
Supplementary Lighting. Mount close to working area.			Metal housing containing either a porcelain enameled or aluminum reflector.	Tubular incandescent or fluorescent lamps.	
Supplementary Lighting for the illumination of vertical surfaces.			Angle reflector. Porcelain enameled steel.	75-watt to 1000-watt general service.	
Supplementary Lighting Spot and Flood			PAR-38 or R-40 spot or flood. The projector and reflector lamps have self-contained reflectors.	150-watt or 300-watt.	Reflectors to be used with general service lamps are available with wide or narrow beams.
Supplementary Lighting			Metal hood 3′ wide by 10′ long with indirect trough suspended below.	Four 200-watt incandescent lamps per 10′.	



5. Inspection Lighting

In designing inspection lighting the following characteristics of the materials or objects to be examined should be considered: (1) composition, (2) finish, (3) form, (4) internal structure, (5) surface contour, (6) color. The lighting must then be tailor-made to fit the seeing task imposed by these characteristics. Generally speaking, a large low-brightness source is best for most inspection work; however, surface irregularities are sometimes easier to detect when light strikes at a grazing angle.

The inspection of transparent materials such as bottles, glassware, plastics, etc., can be accomplished by means of an illuminated inspection panel facing the inspector and projecting light through the object.

LUMINAIRE MOUNTING

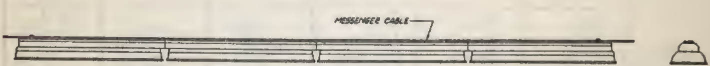
Individual reflectors may be mounted directly on the ceiling, suspended by conduit or chain, or from messenger cable, to the desired mounting height.

Continuous rows of fluorescent fixtures can be mounted in several ways. The various methods are illustrated below.

Fixtures for continuous-row mounting are little more expensive initially than individual fixtures and are considerably less expensive to install. The continuous trough acts as a wire-way, and power need be supplied only at one convenient point along a row.

Although initial requirements may not warrant continuous rows of reflectors, it is good practice to install continuous wiring channels. Additional ballasts and reflectors can then easily be installed if the nature of the work should change so as to require additional illumination.

CONDUIT MOUNTING

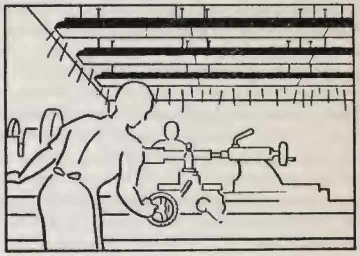


MESSENGER CABLE MOUNTING

TWIN-ROD MOUNTING

CEILING MOUNTING

Orientation of luminaires with respect to the principal line of sight should be such as to provide the maximum shielding of the bare lamps. The light distribution curve of RLM-type fluorescent fixtures is practically the same in the planes parallel and perpendicular to the lamp axis. However, due to the shielding effect of the luminaire itself, the brightness is less annoying when the unit is viewed from the side.



Where luminaires must be mounted parallel to the normal line of sight, reflectors with closed ends should be used since they do afford some shielding. More comfortable conditions can be obtained by installing louvers which provide uniform shielding in all directions.

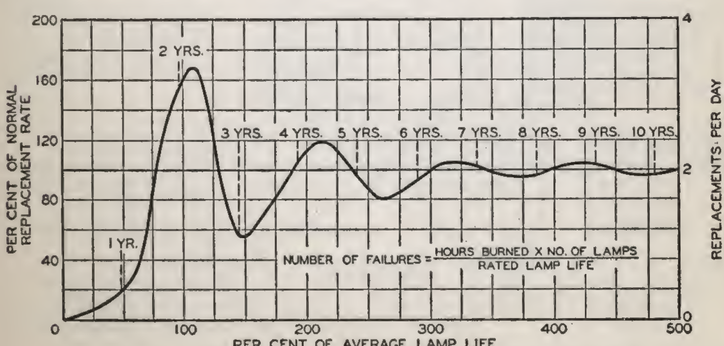
Where it is necessary to read cylindrical or conical dials on machines, best results can be obtained when fluorescent lamps are installed with the long axis perpendicular to the axis of rotation of the dial. Since dials are frequently placed in various planes around the machine, fluorescent luminaires may be installed in a grid arrangement so that their long axes run in two different directions.

MAINTENANCE AND EQUIPMENT

Lamp Replacement

All light sources, incandescent, fluorescent and mercury, have average rated lives under specified operating conditions. Some lamps burn out before this average is reached and others last longer than the average. It is to be expected therefore that there will be a variation in the number of burnouts during the life of an installation.

On new installations it is important to remember that there will be a wide variation in the replacement rate during the first year or two of service. As shown in the chart, in a specific installation of fluorescent



* 1250 LAMPS – BURNED 8 HOURS/DAY, 25 DAYS/MONTH – 5000 HOURS LIFE

lamps (1250 lamps burning 8 hours a day for 25 days a month with an average life of 5000 hours) the normal replacement rate as calculated from the formula is two lamps per day. The "normal rate" is the rate attained after sufficient replacements have been made so that burnouts occur entirely at random. While the lamps are new the replacement rate is well below normal, and as the original group of lamps approach the end of life the rate is at least 50% above normal. Thereafter the rate varies in decreasing amounts above and below normal, until the installation has been in operation sufficiently long for the replacements to approach a constant rate.

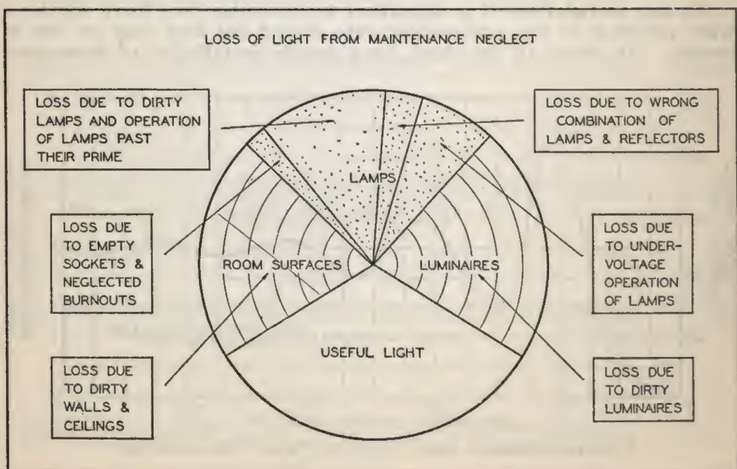
The length of time required to achieve the normal replacement rate varies with the average rated life of the lamps. When fluorescent or mercury lamps are used, the number of hours the lamps are burned at each turn-on has a direct bearing on the life of the lamps. For example, a 40-watt fluorescent lamp burned for 3 hours each time it is turned on will have a life of approximately 2500 hours, whereas the same lamp burned for 12 hours per start will have a life of 6000 hours. For filament lamps the curve will be approximately the same, but the normal rate is reached sooner because of the shorter life of the lamps.

Cleaning

Many modern factories have extremely high ceilings, and special devices are necessary to maintain the lighting equipment. Among these are:

1. Step ladder
2. Extension ladder
3. Telescoping platform
4. Lowering-type hangers
5. Catwalk
6. Traveling crane

The selection of ladders and telescoping platforms will be determined by the amount of space between machines or stock. The other methods mentioned depend on the construction of the building, and no specific instruction can be given. With lowering or disconnecting-type hangers the fixtures can be brought to floor level by means of cords and pulleys.



CHAPTER TEN

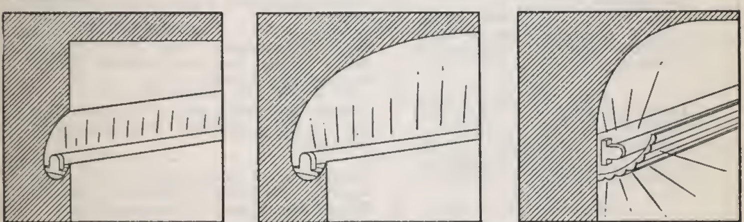
ARCHITECTURAL LIGHTING

Luminous elements, either on the exterior or the interior of a building, which form a part of its structural and decorative details are classified as architectural lighting. It is of necessity custom-built, and may assume many shapes, colors, and forms; it may be in-built or attached to other architectural features; it may function as pure decoration or provide lighting for seeing in a decorative manner; it is a partnership of good taste, artistic design, novelty, and good illuminating engineering.

TYPES OF ARCHITECTURAL LIGHTING

Cove Lighting

A continuous or translucent trough section which conceals the light sources from direct view and directs most of the light towards a reflecting surface which becomes the luminous element is the basic structural feature of cove lighting. Coves may be curved or straight, and arranged in horizontal or vertical lines or at various angles. They are often constructed of plastic, metal, glass or plaster. They may be attached to the walls of a room, to vertical supporting columns, to ceiling beams or ceiling coffers, or arranged along the edge of a dropped ceiling to illuminate the walls of an interior. Reflecting surfaces in combination with coves are generally light in color (for efficiency) and matte or semi-matte in finish. However, spectacular decorative effects may be achieved with backgrounds of stainless steel, polished aluminum, or chromium with brushed or corrugated surfaces.



This form of architectural lighting is very flexible as a decorative luminous element, and can also be used to provide relatively high levels of illumination for seeing.

Luminous Architectural Forms

Luminous in-built panels and rectangular, triangular, and other shapes of translucent projecting elements—of glass, marble or plastic—are standard forms in architectural lighting. These forms may be located in or on walls, ceilings, columns, or supporting members.

If the luminous element is for decoration only, the design should be based on the brightness value desired; if decoration and illumination are required, then the designer must consider the illumination level necessary.

REFLECTING AND TRANSMITTING MATERIALS

Material	Reflection or Transmission	Characteristics
Reflecting		
(a) Specular		
Mirrored Glass	80 to 90%	Provide directiona contro of light and high brightness at specific viewing angles. Effective as efficient reflectors and for special decorative lighting effects.
Alzak Aluminum	75 to 85%	
Polished Aluminum	60 to 70%	
Chromium	60 to 65%	
Stainless Steel	55 to 65%	
Black Structural Glass	5%	
(b) Spread		
Alzak Aluminum (diffuse)	70 to 80%	General diffuse reflection with a high specular surface reflection of from 5 to 10% of the light. Undesirable streaks and high-lights will occur when these materials are used as cove backgrounds. Special decorative band and high-brightness effects may be achieved with these surfaces.
Etched Aluminum	70 to 85%	
Satin Chromium	50 to 55%	
Brushed Aluminum	55 to 58%	
Porcelain Enamel	60 to 80%	
Aluminum Paint	60 to 70%	
(c) Diffuse		
White Plaster	90 to 92%	Diffuse reflection results in uniform surface brightness at all viewing angles. Materials of this type are good reflecting backgrounds for coves and luminous forms.
White Paint (Matte)	75 to 90%	
White Terra-Cotta	65 to 80%	
White Structural Glass	75 to 80%	
Limestone	35 to 65%	
Transmitting*		
(a) Glass		
Clear	80 to 90%	Low absorption; no diffusion; high concentrated transmission. Used as protective cover plates for concealed light sources.
Configurated, obscure, etched, ground, sandblasted and frosted	70 to 85%	Low absorption; high transmission; poor diffusion. Used only when backed by good diffusing glass or when light sources are placed at edges of panel to light the background.
Opalescent and Alabaster	55 to 80%	Lower transmission than above glasses; fair diffusion. Used for favorable appearance when indirectly lighted.
Flashed (cased) Opal	30 to 65%	Low absorption; excellent diffusion. Used for panels of uniform brightness with good efficiency.
Solid Opal Glass	15 to 40%	Higher absorption than flashed opal glass; excellent diffusion. Used in place of flashed opal where a whiter appearance is required.
(b) Plastics	0 to 95%	Available in wide ranges of transmission, diffusion, color, and shapes. Used as a substitute for glass in many instances, except where high temperatures are encountered.
(c) Marble (Impregnated)	5 to 30%	High absorption; excellent diffusion; used for panels of low brightness. Seldom used in producing general illumination because of the low efficiency.
(d) Alabaster	20 to 50%	High absorption; good diffusion. Used for favorable appearance when directly lighted.

*Inasmuch as the amount of light transmitted depends upon the thickness of the material, the figures given are based on thicknesses generally used in lighting applications.

BRIGHTNESS RECOMMENDATIONS

The following conditions have a direct influence on the brightness design of a luminous element:

FOR INTERIORS

a. General Illumination Level as Compared to Brightness of Element—

The greater the general illumination in a room, the higher the brightness of the luminous element has to be to make it outstanding. Eye comfort is imperiled by too great a contrast, if the element is prominently located.

b. Position of the Element—

If the element is out of normal viewing angles higher brightnesses are possible without eye discomfort.

c. Size of the Element—

Large luminous elements may have a lower brightness than small elements and still maintain full effectiveness.

d. Time of Viewing—

If the element is installed where constantly viewed, low brightness is essential for eye comfort.

e. Color of the Element—

The decorative value of color is great, hence brightness may be reduced when color is used.

f. Brightness Uniformity of the Element—

Uniformity of brightness is generally desirable, and lamp spacings should be selected with this in view. If a decorative grille or silhouette is used on the element, rather wide variations in brightness are permissible from the appearance standpoint.

FOR EXTERIORS

a. Brightness of Adjacent Elements or Displays—

The greater the contrast between the element (sign, store front, decoration, etc.) and its surroundings the greater will be its apparent brightness and eye-attracting possibilities.

b. Function of the Element—

The brightness of a sign or advertising message in a luminous element should exceed that of any other part of the display. Luminous elements for decoration on monumental buildings should be lower in brightness than those on commercial buildings.

c. Position of the Element—

The higher the element above eye level the brighter it should be for equal effectiveness. Luminous decorations at the top of a 4-story building should be at least double the brightness of the same element located at eye level.

d. Size of the Element—

Large elements may have a lower brightness without loss of advertising effectiveness.

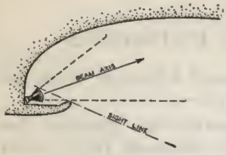
e. Color of the Element—

The greater attraction value of color makes it possible to reduce brightness without loss of effectiveness in signs and luminous advertising displays.

f. Brightness Uniformity of the Element—

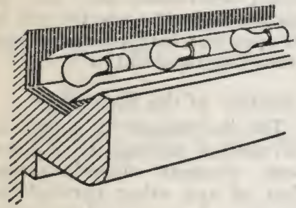
Highlights and sparkle involving the use of metal backgrounds and low diffusion materials may be desirable in exterior luminous elements.

ARCHITECTURAL LIGHTING DESIGN
Cove Lighting Design Suggestions



Sight Lines—

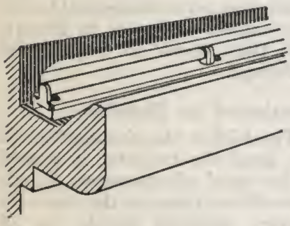
Coves should be so constructed that the lamps are not visible from normal viewing angles. Coves located too close to the ceiling reveal surface irregularities and create dark areas in center of ceiling.



Typical Lamp Arrangements—

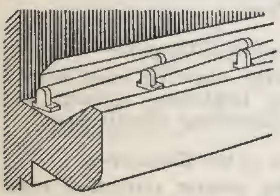
GENERAL SERVICE LAMPS

Proper spacing with auxiliary reflectors to direct light away from surface near lamps will result in an even, attractive appearance free from dark areas.



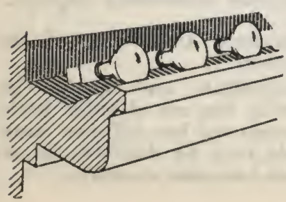
FLUORESCENT & LUMILINE LAMPS

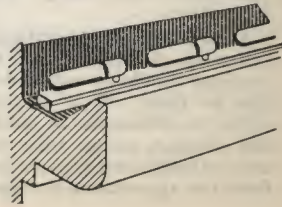
Slight shadows on background will occur at sockets if auxiliary reflectors are not used. By staggering the lamps and overlapping the ends 3″ this spotty "scallop effect" can be eliminated.



REFLECTOR & PROJECTOR LAMPS

Lamps of this type have self-contained reflectors which give some directional control of the light beam. They are used when light must be projected across to the opposite side of the ceiling to obtain an even distribution. The showcase type is suitable for shallow coves where the distance of throw is short; the floodlight type is for larger coves and longer throws.





Cove Lighting Design Procedure

To Provide Illumination for Interiors:

1. **Determine the footcandles required by reference to tables in Chapter Five.**

2. **Select from table below the Cove Lighting Design Factor.**

COVE LIGHTING DESIGN FACTORS*

Color of Ceiling	Color of Walls	Room Proportions		
		Width equals four times ceiling height	Width equals twice the ceiling height	Width equals ceiling height
Very Light	Light	3.5	5.0	6.5
	Medium	4.0	5.5	7.5
	Dark	4.5	6.0	9.0
Medium Light	Light	5.0	6.5	9.5
	Medium	5.5	7.5	11.0
	Dark	6.0	8.5	13.0

*** Depreciation allowance of 70% included.**

3. **Compute total lumens required:**
   Total lumens = Footcandles x Area (sq. ft.) of Room x Design Factor.

4. **Determine number of lamps by dividing total lumens by lamp lumens as given in manufacturer's lamp data catalogs.**

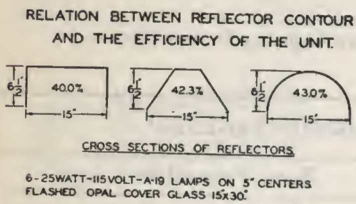
5. **Decide on the spacing—**
   This will depend upon the cove design, the wattage and type of lamp selected, and the number of lamps required. Standard cove design will permit spacings of 12″ to 15″ (from light center to light center), but closer spacings are required in narrow coves with lamps close to the background. Where a single row of lamps does not provide the level required, double rows can be used with correspondingly enlarged coves. If the number of lamps required is too small to fill the cove without too great a spacing, then lower wattage lamps should be used to provide the necessary number to assure uniformity. See suggested lamps and methods on opposite page.

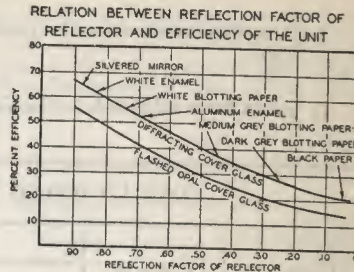
To Provide Decoration of Interiors:

(See Procedure and Tables for Luminous Elements following).

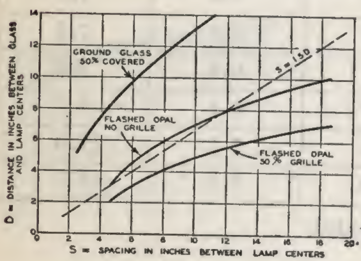
Luminous Element Design Suggestions

REFLECTOR CONTOURS AND FINISHES

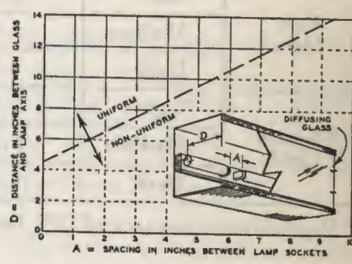




BRIGHTNESS UNIFORMITY AND LAMP SPACING



Spacing of Filament Lamps for Acceptable Uniformity



Spacing of Fluorescent Lamps for Acceptable Uniformity

The shape of the reflector and the general proportions of the unit are the essential factors to consider when determining the spacing of the lamps and the distance of the lamps from the translucent cover or diffusing surface. The permissible spacing between lamps and the distance between the lamps and the cover or background will vary because of the various characteristics and transmission factors of the materials used for cover plates.

The above curves give the permissible values for the spacing of filament lamps and fluorescent lamps for acceptable uniformity. The filament lamp curves also apply to the spacing between parallel rows of fluorescent lamps while the fluorescent curve refers only to the permissible end-to-end spacing for fluorescent lamps.

In general, the spacing between centers of incandescent lamps or between rows of fluorescent lamps should be one and one-half times the distance from the lamp center to the cover plate.

The success of a luminous element depends primarily on its brightness (expressed in footlamberts). A table of suggested brightness values is given on the opposite page.

Luminous Element Design Procedure

To Provide Illumination and Decoration in Interiors:

1. Select the brightness desired from the table of suggested brightnesses.
2. Calculate the total lamp lumens required.

$$\text{Total Lumens} = \frac{\text{Brightness (ft-L) x Luminous Area (sq. ft.)}}{\text{Element Efficiency x Maintenance Factor}}$$

3. To provide brightness uniformity, refer to the Table on Efficiencies of Luminous Elements to compute D (distance of light center to cover glass) and S (spacing of lamps) based on the known width (W) and general shape of the element under consideration.
4. From the values obtained in (3), estimate total number of lamps required.

$$\text{Number of Lamps} = \frac{\text{Length of Element}}{\text{S (spacing of lamps)}}$$

5. Calculate lamp lumens to provide brightness desired at spacings determined in (3).

$$\text{Lumens per Lamp} = \frac{\text{Total Lumens}}{\text{Number of Lamps}}$$

6. Select from manufacturer's lamp data catalogs the lamp that has this lumen output (approximate).

SUGGESTED BRIGHTNESS VALUES FOR LUMINOUS ARCHITECTURAL ELEMENTS

INTERIOR ELEMENTS

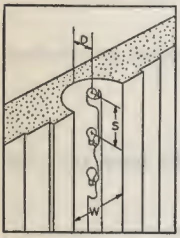
	FOOTLAMBERTS
Ceiling Elements	
High Ceilings (20 feet)	500
Low Ceilings	250
Decorative Panels	
Not in usual line of sight	150
Constantly in view	75

EXTERIOR ELEMENTS

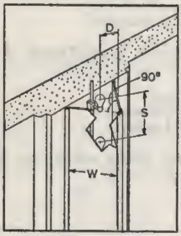
	GENERAL BRIGHTNESS OF DISTRICT		
	Low	Medium	High
Luminous Store Fronts, Backgrounds, Signs, Marquise, Fascias and Soffits	80–150	100–250	200–400
Flushed or Recessed Elements			
Dominant	30–100	50–150	100–300
Subordinate	30–60	40–80	50–150
Projecting Luminous Elements			
Dominant	50–130	70–170	150–300
Subordinate	30–60	40–80	50–150
Luminous Letters	150–200	200–400	300–600

EFFICIENCIES OF TYPICAL FORMS OF LUMINOUS ELEMENTS

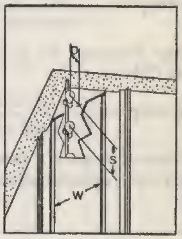
NOTE—The tables to follow apply not only to filament lamps (shown in all diagrams) but also to fluorescent lamps. A single row of 40-watt fluorescent lamps, spaced end to end, provides a brightness roughly equal to that which would be produced by a row of 40-watt filament lamps spaced one foot apart; two parallel rows of 40-watt fluorescent lamps would likewise equal two 40-watt or one 100-watt filament lamp per linear foot, etc. Based upon equal lumens per linear foot, either fluorescent or filament lamps can therefore be used to provide necessary brightness for luminous elements. The lower brightness and greater diffusion of the fluorescent lamp makes possible the use of lighter cover glasses without impairing brightness uniformity. Consult the brightness uniformity curves on page 10—6 for spacing suggestions for fluorescent lamps.



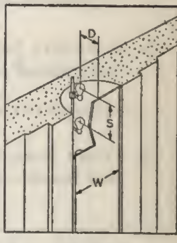
S = 2 D
D = 0.5 W
Efficiency 40%



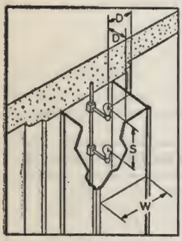
S = 1.5 D
D = 0.5 W
Efficiency
Flashed Opal 65%
Solid Opal 45%



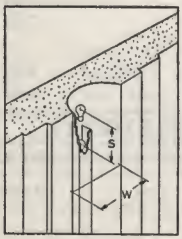
S = 1.5 D
D = 0.4 W
Efficiency
Flashed Opal 50%
Solid Opal 35%



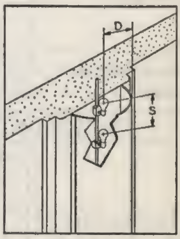
S = 1.5 D
D = 0.67 W
Efficiency
Flashed Opal 50%
Solid Opal 35%



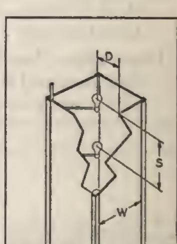
S = 1.5 D
D = 0.5 W
Efficiency
Flashed Opal 75%
Solid Opal 55%



S = D
D = 0.33 W
Efficiency 25%



S = 1.5 D
Efficiency
Flashed Opal 80%
Solid Opal 60%



S = 1.5 D
D = 0.5 W
Efficiency
Flashed Opal 85%
Solid Opal 65%

CHAPTER ELEVEN

FLOODLIGHTING DESIGN

Including Sports Lighting

The lighting of commercial buildings as advertising media, the lighting of sports fields for amateur or professional engagements, and the lighting of construction projects extend the hours in which each of these can be effective. In addition to the more utilitarian applications, floodlighting serves many decorative uses.

The type of area to be lighted, the possible location of equipment, and the variation in surrounding conditions impose problems in design which tend to make standardization difficult. There are, however, certain basic rules which may be followed in installation design.

DESIGN PROCEDURE

Step 1—Determine the level of illumination

In the table are listed the illumination levels for many floodlighting applications. These levels are designated as "footcandles in service," and allowances must be made for reasonable depreciation in the original design.

In lighting buildings, monuments, etc., the reflection factor of the object and the brightness of the surroundings must be considered in order to determine the amount of light necessary.

LEVELS OF ILLUMINATION

	Footcandles Maintained in Service
Automobile	
Used Car Lots—	
Front Row of Cars	50
Remainder of Area	10
Automobile Parking Spaces	2
Building	
Construction	10
Excavation Work	2
Building Exteriors & Monuments—Floodlighted	
Bright Surroundings—	
Light Surfaces . . (80% RF)*	10
Medium Surfaces (40% RF)*	20
Dark Surroundings—	
Light Surfaces . . (80% RF)*	5
Medium Surfaces (40% RF)*	10
Bulletin and Poster Boards	
Bright Surroundings—	
Light Surfaces	50
Dark Surfaces	100
Dark Surroundings—	
Light Surfaces	20
Dark Surfaces	50
Coal Yards—Protective	0.2
Dredging	2
Drill Fields	5
Flags—Floodlighted	30

*Approximate reflection factor.

	Footcandle Maintained in Service
Gasoline Service Stations	
Yard	10
Pump Island and Sales Room	30
Lube Room—	
General	20
Work Area, Repair, and Washing	50
Loading Docks	5
Lumber Yards	1
Monuments (See Building Exteriors)	
Piers	
Freight	5
Passenger	5
Prison Yards	5
Protective Industrial	0.2
Quarries	5
Railroad Yards	
Receiving	0.2
Classification	0.3
Ship Yard Construction	
General	5
Ways and Fabrication Areas	10
Smoke Stacks with Advertising Messages	20
Storage Yards	1
Water Tanks with Advertising Messages	20

LEVELS OF ILLUMINATION (Cont.)

SPORTS LIGHTING

	Footcandles
Badminton	
Tournament	30
Recreational	10
Baseball	
Seats—	
During Game	2
Before and After Game	5

	In-field	Out-field
Major League	150	100
AAA and AA League	75	50
A and B League	50	30
C and D League	30	20
Semi-Pro	20	15
Minimum	15	10

	Footcandles
Basketball	
College and Professional	50
High School	30
Recreational	10
Bathing Beaches	1
Billiards	
General	10
On Tables	50
Bowling	
General	20
On Pins	50
On the Green	10
Boxing	
Seats—	
During Bout	2
Before and After Bout	5
Ring—	
Amateur	100
Professional	200
Championship	500
Clock Golf	10
Croquet	10
Football	
Professional	100
Class A	50
Class B	30
Class C	20
Minimum	10
Gymnasium	
Locker and Shower Rooms	10
Exercising Room, Fencing, Boxing, Wrestling, Basketball, Volley Ball, Soft Ball and General Exercise	20
Exhibition Games and Matches	30
Handball	30
Hockey	
College and Professional	50
Recreational	10
Horseshoe Pitching	10
Playgrounds	5
Polo	10
Race Tracks	
Seats	2
Track	20
Rifle Range	
On Target	50
Firing Point	10
Range	5
Roque	20
Shuffleboard	20
Skating Rink	
Indoor	10
Outdoor	2
Soccer	
College and Professional	30
High School	20
Athletic Field	10
Skeet	
Vertical Surface at 100 Feet	30

Softball

	In-field	Out-field
Professional	50	30
Class A	30	20
Class B	20	10
Class C	10	5

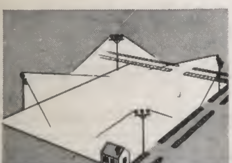
	Footcandles
Squash	
Tournament	30
Recreational	10
Swimming Pools	
General	10
Table Tennis—Ping Pong	50
Target Shooting (On Target)	50
Tennis	
Recreational	20
Exhibition Matches	30
Toboggan Slides	2
Trap Shooting	
Vertical Surface at 150 Feet	30
Volley Ball	
Recreational	10
Exhibition Matches	20

Step 2—Determine the location and type of floodlights

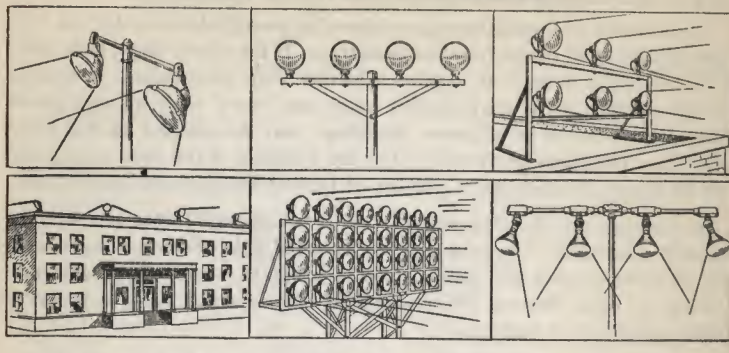
The location of floodlighting equipment is usually dictated by the type of application and the physical surroundings. If the area is large, individual towers or poles spaced at regular intervals may be required to light it evenly; smaller areas may require only one tower with all equipment concentrated on it; or adjacent buildings may be utilized as floodlight locations. The chart below will aid in the selection of the right equipment and its proper location for a number of typical floodlighting applications.

In planning any floodlighting system it is important that the light be properly controlled. Powerful and uncontrolled light thrown along a highway or railroad track will produce dangerous glare to oncoming traffic, and a blaze of light thrown indiscriminately on adjacent private property might constitute a nuisance.

TYPICAL FLOODLIGHTING APPLICATIONS

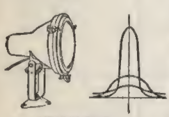
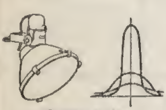
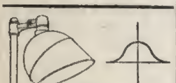
Representative Application	Class of Equipment	Location of Equipment	Maintained Level of Illum.	Watts/Sq. Ft. for White Light
	Closed Type Medium or Wide Beam, or Open Type Wide Beam	At edge of area, and mounted as high as possible.	1 ft-c	.15
	Closed Type Medium or Wide Beam	Mounted in rows immediately inside and below parapet.	15 ft-c	2.3
	Closed Type Medium or Wide Beam, or Open Type Wide Beam	At edge of area, or where they will not hinder traffic.	10 ft-c	1.5 For area of drives plus area of building.
	Closed Type Medium or Wide Beam, or Projector Lamps	On ground 5′ to 25′ from vertical surface.	50 ft-c	7.5

SUGGESTED MOUNTING METHODS



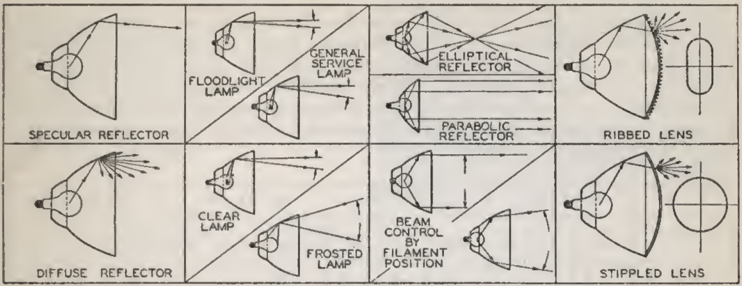
Enclosed floodlights are necessary where rain or snow would cause damage to the lamp or reflector or where accurate beam control is desired. The general purpose floodlight is one in which the inner surface of the housing serves as the reflecting surface. The 'heavy duty' type is more rugged since its aluminum or glass reflector is protected by a metal housing.

DATA ON TYPICAL FLOODLIGHT EQUIPMENT

	*Beam Spread	Lamp	Advantages	Typical Beam Lumens		
				500 W	1000 W	1500 W
 HEAVY DUTY	Narrow 30° or Less	Floodlight or Clear General Service	Good light control, dust-tight cover, low maintenance cost.	4,200	8,500	14,000
	Medium 30°–65°	Clear General Service		4,700	9,500	16,500
	Wide 65° or More	General Service		5,200	11,000	18,000
 GROUND AREA ENCLOSED				1000 W	1500 W	
	Narrow 30° or Less	Floodlight or Clear General Service	Good light control, weatherproof, easily serviced. Good lamp burning position. High efficiency.	10,500	16,000	
	Medium 30°–65°	Clear General Service		12,100	17,800	
	Wide 65° or More	General Service		13,200	19,000	
 GROUND AREA OPEN				1000 W	1500 W	
	Wide (55°–130°)	General Service	Light weight, low initial cost.	9,000	14,000	
 PROJECTOR LAMP				150 W		
	Medium (35°)	Projector Spot	Low cost, small size, efficient, low maintenance cost.	990 (0° to 15°)		
	Wide (80°)	Projector Flood		1150 (0° to 30°)		

* The beam spread of a floodlight is the angle enclosed by two lines which intersect the distribution curve at the points where the candlepower is equal to 10% of its maximum.

ELEMENTS CONTROLLING BEAM SPREAD



***APPROXIMATE BEAM SPREADS OF TYPICAL FLOODLIGHTS**

Lamp Types	Enclosed Type Narrow Beam Reflector			Enclosed Type Wide Beam Reflector			Open Type
	Plain Lens	Stippled Lens	Spread Lens	Plain Lens	Stippled Lens	Spread Lens	
General Service	23°x23°	40°x40°	25°x46°	75°x75°	83°x83°	75°x85°	40°x40° to 125°x125°
Floodlight	13°x13°	33°x33°	13°x40°				

*For more exact data on beam spreads refer to manufacturers' catalogs.

Step 3—Determine the number of floodlights required

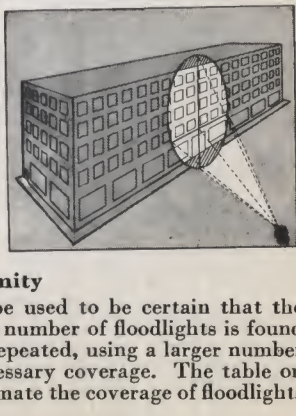
$$\text{Number of Floodlights} = \frac{\text{Area x Footcandles}}{\text{Beam Lumens x M.F.}}$$

Area—Surface area to be lighted in square feet.

Footcandles—As selected from table on pages 11—1 and 11—2.

Beam Lumens—Refer to manufacturer's catalog for equipment under consideration.

M.F.—Maintenance Factor; represents an allowance for depreciation in service (.65 for open type and .75 for enclosed type floodlights).



The result of this calculation will have to be modified where all of the beam lumens do not fall on the area. This can best be done by making a scale drawing which will reveal how much of the total light output is utilized.

Step 4—Check for coverage and uniformity

A graphic check of this nature should be used to be certain that the area will be uniformly covered. Where the number of floodlights is found to be inadequate Step 3 may have to be repeated, using a larger number of smaller units in order to obtain the necessary coverage. The table on pages 11—6 and 11—7 may be used to estimate the coverage of floodlights with various beam spreads.

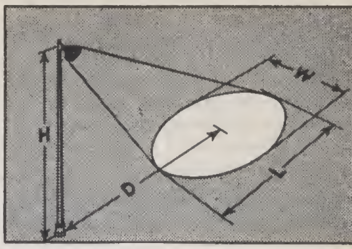
FLOODLIGHT COVERAGE

The area effectively covered by a floodlight will vary with the beam spread of the equipment and its distance from the area to be lighted. The following table provides information as to the size of the lighted areas for various floodlight positions. To get complete coverage of an area where several units are employed the light beams must overlap. The area covered by each floodlight is necessarily reduced and this has been taken into account in the following table.

H	D	10° BEAM			15° BEAM			20° BEAM			25° BEAM		
		Area	L	W	Area	L	W	Area	L	W	Area	L	W
	0	5	3	3	10	4	4	18	5	5	30	7	7
	10	8	4	3	20	6	5	33	8	7	50	10	8
15	20	21	7	4	50	11	7	93	16	9	160	20	12
	30	52	14	6	130	21	9	250	30	13	460	41	17
	40	113	22	8	290	37	12	620	55	17	1300	83	23
	0	11	4	4	25	7	7	44	9	9	70	11	11
	20	23	7	5	50	11	8	100	15	12	150	19	14
25	40	71	16	8	160	25	13	330	34	17	540	45	22
	60	195	31	11	490	49	18	1030	73	25	1960	105	34
	80	450	54	15	1200	90	24	2920	145	36	7270	251	53
	0	38	9	9	90	13	13	155	18	18	210	20	20
	20	47	11	9	110	15	14	195	21	19	320	26	24
50	40	81	14	11	190	22	17	330	30	23	550	38	29
	60	150	22	14	340	33	20	630	45	28	1070	58	36
	80	260	32	17	600	49	25	1160	68	35	2060	90	45
	0	67	13	13	170	20	20	310	26	26	480	33	33
	40	110	17	14	250	25	22	440	34	30	710	43	38
75	80	220	28	18	540	43	29	1010	59	39	1630	75	50
	120	530	48	25	1210	74	38	2320	102	52	3930	135	67
	160	1040	76	32	2500	119	49	5050	171	67	9060	238	88
	0	120	17	17	310	26	26	490	35	35	770	44	44
	40	150	20	19	390	31	28	610	41	38	980	52	48
100	80	250	29	22	580	44	34	1050	59	46	1700	75	58
	120	470	43	28	890	66	41	2000	90	56	3290	116	72
	160	830	63	33	1950	98	51	3700	136	69	6340	180	89
	200	1300	80	42				6650	201	84			
	0	270	26	26	610	39	39	1100	53	53	1740	67	67
	40	300	28	27	680	42	41	1230	57	55	1940	71	69
150	80	400	34	30	900	51	45	1630	69	60	2580	87	76
	120	570	43	34	1310	65	51	2380	89	68	3820	113	87
	160	860	57	39	1970	86	58	3610	117	79	5920	151	100
	200	1280	74	44				5550	156	91			
	0	480	35	35	1090	53	53	1940	71	71	3090	89	89
	40	510	37	36	1160	55	54	2080	73	72	3280	92	91
200	80	600	41	38	1360	61	57	2470	82	77	3910	104	96
	120	770	48	41	1730	72	61	3160	97	83	5030	123	104
	160	1030	58	45	2330	87	68	4240	118	91	6800	150	115
	200	1370	71	50				5800	146	102			
	0	1080	52	52	2460	79	79	4400	106	106	6940	133	133
	40	1110	53	53	2520	80	80	4520	108	107	7140	136	134
300	80	1200	56	54	2720	85	82	4890	114	110	7740	143	138
	120	1350	61	57	3070	92	85	5530	123	114	8790	156	144
	160	1580	68	60	3590	102	90	6480	137	120	10300	173	152
	0	3010	87	87	6810	132	132	12200	176	176	19300	222	222
	40	3030	88	88	6870	133	132	12300	177	177	19500	223	222
500	80	3120	90	89	7070	135	133	12700	181	179	20100	228	225
	120	3270	93	90	7410	139	135	13300	187	181	21100	235	228
	160	3490	97	92	7900	145	138	14200	195	195	22500	246	233

H = Perpendicular distance from the plane of the surface to the location of the floodlight.

D = Distance from the center of the area being lighted to the perpendicular.



H	D	30° BEAM Area	L	W	35° BEAM Area	L	W
15	0	45	8	8	60	9	9
	10	80	12	10	110	14	12
	20	240	26	14	360	32	17
	30	790	56	21	1430	79	27
	40	2900	133	33	8690	262	50
25	0	100	13	13	140	16	16
	10	140	16	15	170	19	17
	20	220	23	18	310	28	20
	30	430	36	21	660	45	27
	40	920	59	28	1430	75	34
	50	1930	94	37	3270	131	45
	60	3950	155	46	8590	249	63
50	0	350	27	27	510	32	32
	20	450	33	29	650	37	34
	40	800	46	35	1160	55	41
	60	1590	73	44	2440	90	53
	80	3200	117	56	5300	151	69
75	0	700	40	40	970	47	47
	20	790	43	42	1070	51	49
	40	1060	53	46	1460	63	54
	60	1590	69	53	2200	83	61
	80	2480	93	61	3620	114	73
	100	4000	128	72	5780	160	84
	120	6400	175	84	10100	226	103
100	0	1130	54	54	1560	63	63
	40	1430	63	58	1980	74	68
	80	2550	92	70	3560	110	82
	120	5050	146	89	7510	180	106
	160	10300	234	112			
125	0	1760	67	67	2440	79	79
	40	2130	73	71	2870	88	83
	80	3090	97	80	4350	116	96
	120	5200	138	96	7430	167	113
	160	9140	200	116			
150	0	2540	80	80	3510	95	95
	40	2880	86	85	3900	102	97
	80	3820	105	92	5300	125	108
	120	5700	135	107	8000	166	123
	160	10300	234	112			
200	0	4500	107	107	6250	126	126
	40	4800	111	109	6660	132	129
	80	5700	125	116	7950	149	136
	120	7500	150	127	10300	178	148
	160	10200	184	141			

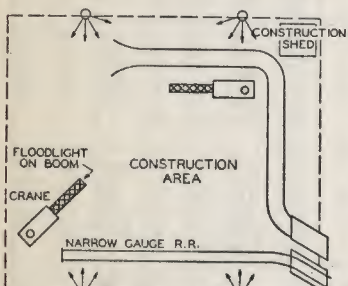
H	D	40° BEAM Area	L	W	50° BEAM Area	L	W
15	0	80	11	11	130	14	14
	5	110	13	12	175	17	16
	10	150	17	14	260	22	18
	15	310	25	19	530	33	25
	20	630	43	23	1250	63	30
	25	1150	65	27			
25	0	185	18	18	305	23	23
	10	240	22	20	400	28	26
	20	450	33	24	800	44	32
	30	970	55	32	2050	83	44
	40	2300	98	42	6950	187	66
	50	6450	194	60			
35	0	320	26	26	520	33	33
	10	380	28	27	580	37	34
	20	510	35	32	890	47	39
	30	850	49	35	1550	67	47
	40	1490	71	43	3000	105	59
	50	2700	106	52			
45	0	470	33	33	780	42	42
	10	520	35	34	820	44	42
	20	650	40	37	1070	52	47
	30	890	49	42	1550	67	53
	40	1320	66	46	2460	91	62
	50	2100	87	55			
55	0	640	40	40	1030	51	51
	20	790	46	44	1300	59	56
	40	1320	66	51	2330	88	68
	60	2650	104	65	5250	152	88
	80	5600	172	83			
70	0	1020	51	51	1680	65	65
	20	1180	55	54	1940	72	69
	40	1680	71	60	2860	93	78
	60	2700	98	70	5000	135	94
	80	4700	142	84			
85	0	1500	62	62	2460	79	79
	20	1680	67	64	2750	85	82
	40	2130	78	69	3600	102	90
	60	3080	100	78	5400	133	103
	80	4750	132	92			
	100	7500	181	106			
100	0	2100	73	73	3400	93	93
	20	2280	78	74	3700	98	96
	40	2700	86	79	4500	112	102
	60	3500	104	87	7800	138	113
	80	5000	130	98			
	100	7300	168	110			

APPLICATION INFORMATION

There can be little standardization in floodlighting application due to the wide variation in the physical characteristics of individual areas. There are, however, some general rules which when properly adapted to the requirements of specific applications will aid materially in obtaining proper illumination.

Building and Dam Construction, and Excavation

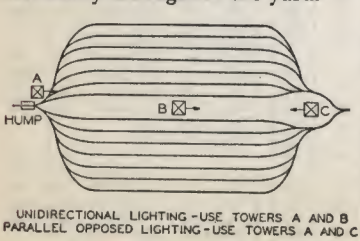
Approximately one 1500-watt, two 1000-watt or three 500-watt units will be required for each 5000 square feet of excavation area or for each 1000 to 2000 square feet of building construction area. It is usually most satisfactory to mount floodlights in groups of two or more on wood poles or towers 40 to 70 feet above ground. A minimum of two poles should be used, with enough poles on larger jobs to provide coverage at any working point from two or three floodlight banks. Fixed-pole spacing may be from 1½ to 3 times mounting height, and as much as 5 times mounting height on large projects. Occasionally it is practical to provide one or two portable poles mounted on timber sled bases which can be dragged from point to point by trucks or tractors. Where a mechanical shovel or crane is used it is advisable to mount an automatic levelling floodlight on the boom.



Since these projects are of a temporary nature, and since the floodlights and poles may have to be moved from time to time, units of the lighter weight type are usually satisfactory. However, if rough mechanical treatment is anticipated, heavy-duty type floodlights should be used.

Railway Yards

An estimate of the number of floodlights required to light a railroad yard may be obtained by the general method of calculation explained previously. The relatively low intensities provided require few floodlights, the size depending on the tower spacing necessary to obtain the desired uniformity throughout the yard.



UNIDIRECTIONAL LIGHTING - USE TOWERS A AND B
PARALLEL OPPOSED LIGHTING - USE TOWERS A AND C

RAILROAD CLASSIFICATION YARD

There are two general types of yard lighting, unidirectional and parallel opposing systems.

The unidirectional system is applicable only to tracks on which the traffic is all in one direction, the light being projected with the traffic flow. Glare is entirely eliminated, although seeing is entirely by direct light without the advantages of silhouette effect.

The parallel opposing system is

used where traffic flows in both directions, which is more frequently the case in actual practice. Here seeing is accomplished by direct light from the tower behind the observer and by silhouette of cars and glint from the rails produced by light from the tower in front of the observer. There is, of course, danger of glare when looking in either direction, which may be minimized by adequate mounting heights.

Selection of tower locations is the most important part of the design procedure, but cannot be specified by rigid rules since track layouts, operating methods, and available space for towers vary for every yard.

A few general rules may be summarized as follows:

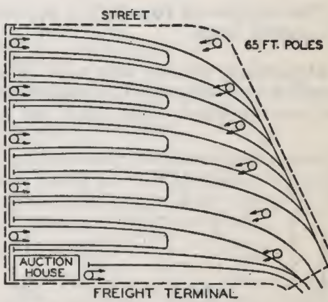
1. The first tower in the classification yard should be near the ladder tracks but on the approach side of the hump, so that spill light or a separate floodlight, if necessary, illuminates the hump area.
2. Narrow yards may be lighted by single towers located on the center line.
3. Wide yards should have two towers abreast of each other, each about one-fourth the yard width from the edges.
4. Tower spacings may follow the general rule of:
   1000-2000 feet max.—parallel opposing system
   800-1000 feet max.—unidirectional system

The relatively long spacing between towers makes it necessary to direct floodlight beams at acute angles with the ground. To minimize glare and shadows, high mounting heights are necessary. Except for spacings well below the maximum values listed above, a height of 90 feet should be considered as a minimum.

Heavy-duty enclosed cast aluminum floodlights are universally used to withstand the operating conditions encountered in railroad service.

Freight Terminals

The lighting of outdoor freight terminals without covered platforms is an application similar to that of railroad yards except that the intensities must, of course, be much higher. A partial plan view of a typical terminal is shown. Vehicular traffic on the platform precludes any possibility of installing poles at locations other than at the ends. To avoid shadows thrown by cars standing on the tracks, it is necessary to place the poles in line with each platform. Mounting heights of from 60 to 80 feet are required, depending on the average length of throw. Heavy-duty floodlights are recommended, as for other railroad service.



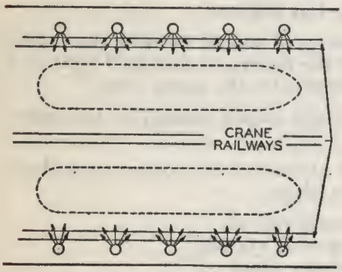
Shipways

Floodlighting for shipbuilding ways usually consists of providing a general illumination of adequate intensity over the entire way by mounting the units at an adequate height along both sides.

When the ways are paralleled by trestles for traveling cranes, the girders

just below the track make ideal locations for mounting the floodlights. The general illumination so provided may be supplemented by several additional floodlights on the crane arm or its support, lighting the particular area over which the crane is working.

Another type of way construction is frequently employed. Here tracks parallel the ways on each side for railway cranes and cars to move the parts used in construction. Pole locations required for the floodlights are necessarily limited to points where they do not interfere with the cranes, making it necessary to design each particular application according to the yard layout.



SHIPWAYS FLOODLIGHTING

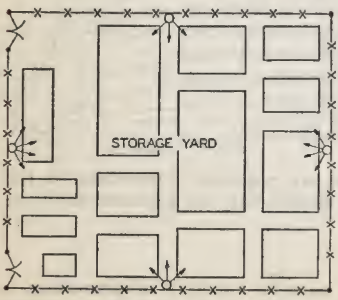
Shipways are provided with electrical distribution systems with weatherproof receptacles at intervals for making connections to electrically operated tools. The general lighting may therefore be supplemented by lights on portable stands, which become necessary at some points as the hull construction approaches its final stages and parts of the interior are in shadow.

Either open or closed 1,000- or 1,500-watt wide beam floodlights are employed for this application. The units should be mounted at least 60 feet high, on trestles or poles, spaced at not over 1½ times the mounting height.

Storage and Handling of Materials

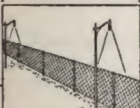
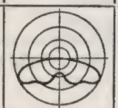
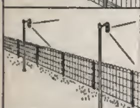
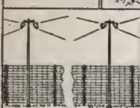
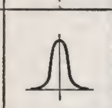
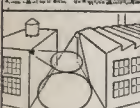
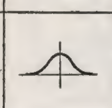
The number of floodlights are to be calculated on an area and average footcandle basis.

Depending on the size and distribution of materials which are to be handled and identified at night, two methods may be used to floodlight the storage yard. The first, for small or average areas, is by means of standard crosslighting from banks of 2 floodlights each on 25- to 40-foot poles along the sides of the yard. The second, where large yards are involved, is by means of higher mounted (50 to 70 feet) banks of four or more floodlights to cover large areas and large materials.



Mounting height and pole spacing will depend on depth and width of spaces between material piles, choice of pole locations being such as to minimize aisle shadows. Poles must not interfere with truck aisles, etc., for handling materials. Although general purpose floodlights will prove satisfactory, the heavy-duty type is recommended for permanent installations.

Protective Lighting—Protection as well as utilitarian light is provided in some plants by floodlighting the entire area. Where it is not practicable or necessary to light so much area the illumination may be confined to the perimeter of the property. The use of proper equipment will allow the guards to observe approaching trespassers without being seen. In addition to the various types of equipment shown below projector lamps may be employed.

Representative Application	Equipment	Light Distribution	Mounting Data	Lamp Size	Horizontal Ft-c	Load Watts per Ft. (Linear)
			10′ inside fence, 25′ high, 125′ apart.	300-watt or 6000-lumen	.18	2.4
				500-watt or 10000-lumen	.31	4.0
			Directly over fence, 25′ high, 125′ apart.	300-watt or 6000-lumen	.20	2.4
				500-watt or 10000-lumen	.34	4.0
			15′-20′ inside fence, 20′ high, 125′ apart.	300-watt or 6000-lumen	.30	2.4
				500-watt or 100000-lumen	.51	4.0
			4′-5′ behind fence, 30′ high, 300′ to 400′ apart.	500-watt	.20	3.3
				1000-watt	.30	5.0
			On buildings 25′ to 50′ high, 100′ to 200′ apart.	200-to 1000-watt	.25	

FLOODLIGHTING DESIGN NOTES

Color—It is usually desirable to experimentally determine the exact amount of colored light necessary for any particular application. Typical commercial filters used with 150-watt projector lamps will produce the following percentages of the illumination obtained with no filter.

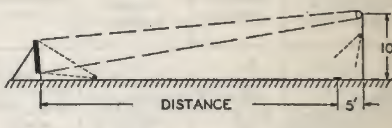
Amber	57%	Red	13%
Green	32%	Blue	9%

Mercury Floodlighting—This type of floodlighting finds its greatest application in gas station lighting and certain types of decorative floodlighting, being particularly effective on lawns and shrubbery because of its distinctive blue-green color. Its color and low operating cost are the chief advantages of mercury lighting.

Fluorescent Floodlighting—Being an extended source of low brightness, the fluorescent lamp does not lend itself to the projection of light for long distances, and for outdoor applications is further hampered by difficulty in starting in cold weather. However, it does produce colored light very efficiently. For further details, see Chapter Three.

ARCHERY

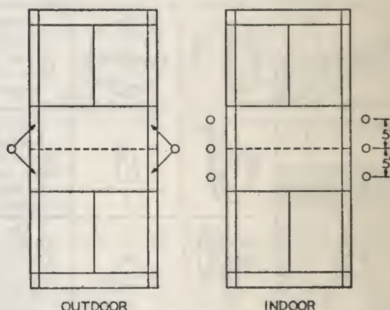
The floodlight provides visibility of the arrow throughout flight.



BADMINTON

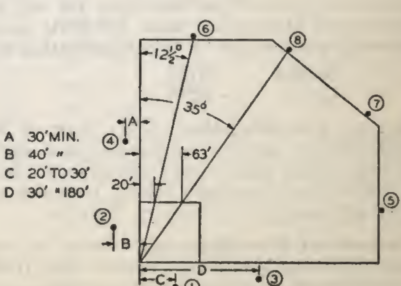
Outdoor
Lighted from poles located at the net.

Indoor
Lighted by suspension type industrial diffusing units along the sidelines.



BASEBALL

The level of illumination is determined by the class of play.



Floodlights	Per Target 1 Enclosed, Beam Spread 12° to 20° 2 PAR-38 Projector Spots 1 PAR-38 Projector Flood
Lamps	For Enclosed Floodlight 250-Watt G-30 Bulb — Up to 30 yards 500-Watt G-40 Bulb — 30 yards to 50 yards 1000-Watt G-40 Bulb — 50 yards to 100 yards PAR-38 150-Watt Projector Flood 150-Watt Projector Spot
Mounting Height	Enclosed Floodlight 10 Feet Above Ground PAR-38 Flood on Same Pole 8 Feet Above Ground PAR-38 Spots on Ground About 10 Feet in Front of and on Either Side of Target
Poles	One per Target

Outdoor

Floodlights	4 per Court, Closed or Open Type, Beam Spread 65° or More
Lamps	*750-Watt General Service PS-52 Clear Bulb
Load	3.0 to 3.5 Kw per Court
Mounting Height	25 Feet
Poles	2 per Court

Indoor

Equipment	500-Watt Glassteel Diffusers, 6 per Court
Lamps	*500-Watt General Service PS-40 Bulb
Load	Single Court 3.0 to 3.5 Kw Double Court 4.5 to 5.2 Kw
Mounting Height	20 to 25 Feet

Class	No. of 1500-Watt Floodlights	Kw at 10% Overvoltage	Mtg. Hgt. to Top of Towers or Poles (Feet)
Major League	750	1305	150
AAA & AA	400	696	120
A & B	240	418	100
C & D	160	278	80
Semi-Pro	120	209	80
Minimum	100	174	60-80

Distribution of Floodlights

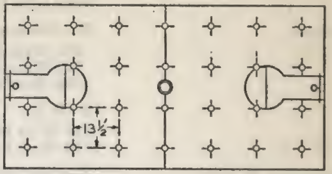
Poles	% Units
1, 2, 5, 6, 7, 8	10%
3 & 4	20%

Lamps *1500-Watt General Service PS-52 Clear Bulb

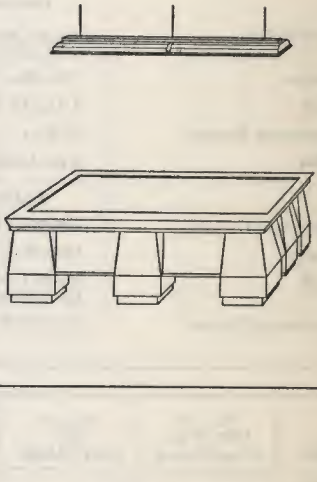
* For under 200 hours' use per year, operate lamps at 10% overvoltage.
For over 200 hours' use per year, operate lamps at 5% overvoltage.

BASKETBALL

If ceiling is lower than 20 feet more units on closer spacing should be used and recessed in the ceiling if possible.



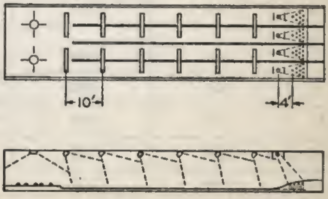
BILLIARDS



In large commercial parlors where a number of tables are installed, general illumination of high intensity proves more satisfactory than individual luminaires over each table.

BOWLING ALLEYS

Luminaires should be positioned so as to provide even illumination along the alley with higher intensity on the pins. Behind the foul line any type of general area lighting equipment may be employed.



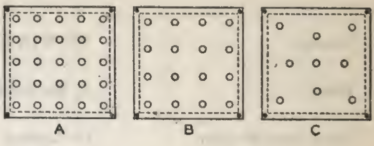
Floodlights	**28 per Court, Deep Bowl Medium Spread Reflectors Mounted on Ceiling or Girders**
Lamps	**750-Watt General Service PS-52 Bulb**
Load	**21 Kw per Court**
Mounting Height	**On Ceiling**

Equipment	**2 Two-Lamp Fluorescent Fixtures with Louvers**
Lamps	**40-Watt T-12 White Fluorescent**
Load	**200 Watts**
Mounting Height	**9 Feet—Above Floor**

Equipment	**6 Two Lamp Asymmetric Type Fluorescent Units 4 Feet Long** **300-Watt R-40 Reflector Floods Over Pins**
Lamps	**40-Watt T-12 White Fluorescent**
Load	**1200 Watts per Pair of Alleys**
Mounting Height	**9 Feet Minimum**

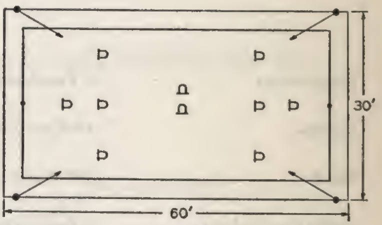
BOXING

The class of bout will determine the level of illumination.



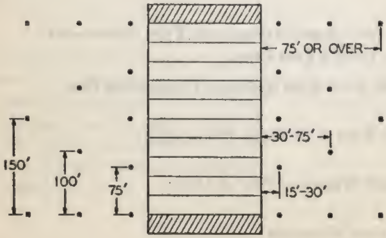
CROQUET

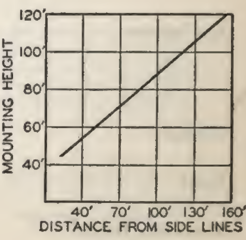
Equipment located in this manner provides an adequate intensity for recreational play.



FOOTBALL

Where open-type floodlights are used it is desirable to use hard glass lamps to prevent breakage in bad weather.





Plan	No. of Units	Load	
		1000-W 110%	1500-W 110%
A	25	29 kw	44 kw
B	16	19 kw	28 kw
C	9	11 kw	16 kw

Equipment	**Deep Bowl Medium Spread Reflectors**
Lamps	***1000-Watt or 1500-Watt General Service PS-52 Bulb**
Mounting Height	**20 Feet.**

Floodlights	**4 per Court, Open or Closed Floodlights, Wide Beam**
Lamps	**300-Watt or 500-Watt General Service PS Clear Bulb**
Load	**1.2 Kw or 2 Kw per Court**
Mounting Height	**20 to 25 Feet Above Ground**

Class	Distance from Sideline	No. of Poles	Floodlights 1500-Watt		Kw at 10% Over-Voltage
			Units per Pole	Total Units	
A	30′ or less	10	12	120	208
	30′ to 75′	8	16	128	223
	75′ or more	6	24	144	250
B	30′ or less	10	8	80	139
	30′ to 75′	8	12	96	167
	75′ or more	6	18	108	188
C	30′ or less	10	6	60	104
	30′ to 75′	8	9	72	125
	75′ or more	6	14	84	146
Minimum	30′ or less	10	4	40	70
	30′ to 75′	8	6	48	84
	75′ or more	6	9	54	94

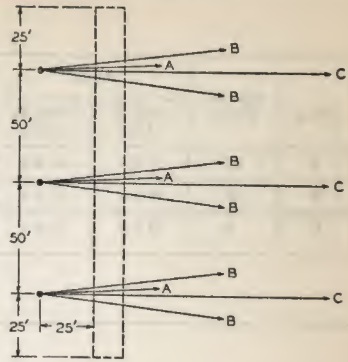
Distance from Sideline	30′ or less	30′ to 60′	60′ to 90′	90′ or more
Beam Spread	65° or more	40° to 65°	25° to 40°	10° to 25°

Lamps *1500-Watt General Service PS-52 Clear Bulb

* For under 200 hours' use per year, operate lamps at 10% overvoltage.
For over 200 hours' use per year, operate lamps at 5% overvoltage.

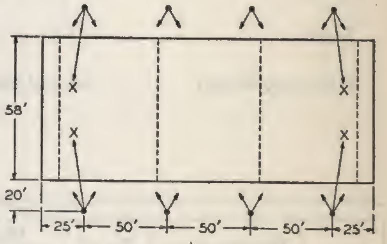
GOLF DRIVING RANGE

The floodlights should be directed so as to provide illumination on the ball throughout its flight.



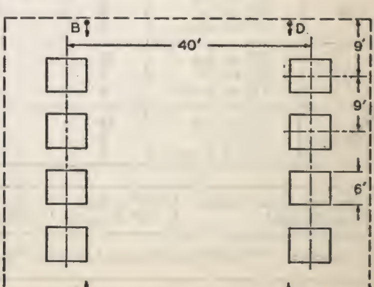
HOCKEY, OUTDOOR

This layout covers the lighting of an outdoor area used for amateur play. Professional indoor hockey requires higher levels of illumination and is usually taken care of by the regular lighting in the fieldhouse.



HORSESHOE PITCHING COURT

Floodlights should be directed across courts to prevent direct glare from luminaires.



Floodlights	A One 1500-Watt, Beam Spread 65° or More B One 1500-Watt, Beam Spread 25° to 40° C Three 1000-Watt, Beam Spread 10° to 25°
Lamps	1500-Watt General Service PS-52 Clear Bulb 1000-Watt Floodlight Service G-40 Clear Bulb
Load	7.5 Kw per Pole
Mounting Height	30 Feet Above Ground
Poles	One for Every 50 Feet of Width

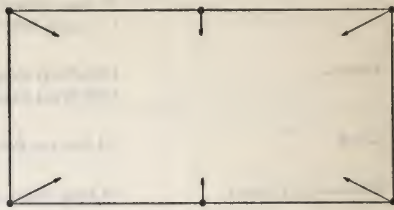
Floodlights	16 1500-Watt, Beam Spread 65° or More 4 1000-Watt, Beam Spread 25° to 40° (Marked "X" on Drawing)
Lamps	*1500-Watt General Service PS-52 Clear Bulb *1000-Watt General Service PS-52 Clear Bulb
Load	32.5 Kw (10% Overvoltage) 30.2 Kw (5% Overvoltage)
Mounting Height	40 Feet Above Ground
Poles	8

Floodlights	Beam Spread 65° or More 2 Required for 1 to 3 Courts 4 Required for 4 to 8 Courts
Lamps	500-Watt General Service PS-52 Clear Bulb for 1 to 3 Courts 1000-Watt General Service PS-52 Clear Bulb for 4 to 8 Courts
Load	1 to 4 Kw
Mounting Height	20 Feet above Ground
Poles	2 or 4 A and D for 1 to 3 Courts A, B, C, D for 4 to 8 Courts

* For under 200 hours' use per year, operate lamps at 10% overvoltage.
For over 200 hours' use per year, operate lamps at 5% overvoltage.

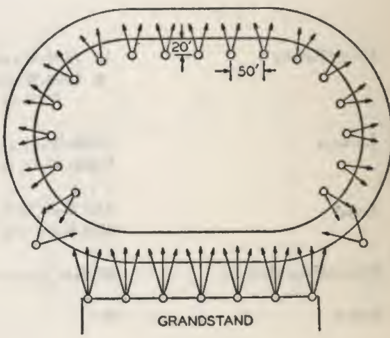
ICE SKATING RINK

The design suggested produces satisfactory illumination for recreational skating on an outdoor pond.



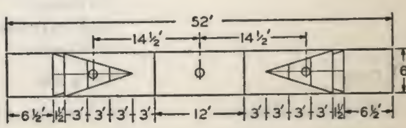
RACETRACKS

The lighting equipment should be so positioned and directed as to keep glare and shadows at a minimum.



SHUFFLEBOARD

Similar equipment should be installed for each court where multiple courts exist.



Floodlights	**Beam Spread 65° or More**
Lamps	**1500-Watt General Service PS-52 Clear Bulb**
Load	**0.25 Watts per Square Foot of Area**
Mounting Height	**25 Feet Minimum, or Not Less Than ¼ of the Spacing**
Poles	**Spacing Not to Exceed 4 Times the Mounting Height**

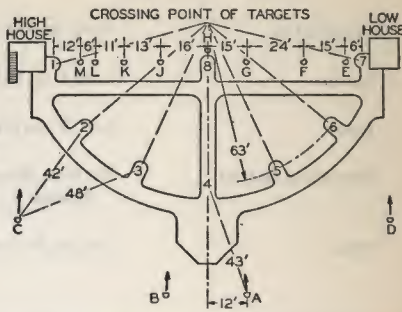
Floodlights	**Narrow Beam Enclosed Type Floodlight with Horizontal Spread Lens. For wide tracks use stippled lens**
Lamps	***1500-Watt General Service PS-52 Clear Bulb**
Load	**Varies with Track Size**
Mounting Data	**40 Feet High and 20 Feet Inside Inner Side of Track**

Floodlights	**3 Medium Spread Glassteel Diffusers**
Lamps	**500-Watt General Service PS-40 Bulb**
Load	**1.5 Kw**
Mounting Height	**12 Feet**

*** For under 200 hours' use per year, operate lamps at 10% overvoltage.**
For over 200 hours' use per year, operate lamps at 5% overvoltage.

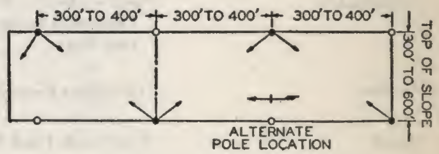
SKEET SHOOTING

Floodlights beams are selected to provide uniform coverage to prevent an apparent variation in bird speed.

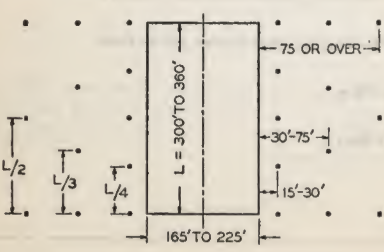


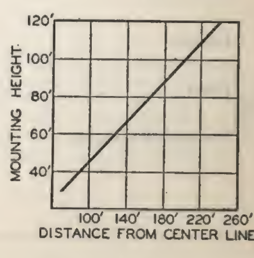
SKI SLOPE

To minimize glare the larger lamps should be directed down the slope.



SOCCER





Floodlights	4 Enclosed 1000-Watt, Beam Spread 50° or More and 8 Enclosed 500-Watt, Beam Spread 65° or More
Lamps	4 *1000-Watt General Service PS-52 Clear Bulb 8 *500-Watt General Service PS-40 Clear Bulb
Load	11.6 Kw at 10% Overvoltage
Mounting Height	24 Feet

Visor shields should be provided for the sides of Floodlights C and D next to the firing positions. Floodlights E to M may be shielded by shrubbery.

Focusing		
Floodlight	**Direction**	**Elevation**
E	10° Left	18° Up
F	5° Left	29° Up
G	30° Right	43° Up
HJKL	Straight	45° Up
M	30° Left	55° Up

Floodlights	500-Watt, Beam Spread 50° or More 1000-Watt, Beam Spread 50° or More 1500-Watt, Beam Spread 50° or More
Lamps	*500, 1000, and 1500-Watt General Service PS Clear Bulb
Load	0.03 Watts per Sq. Ft. of Area (1 Watt Uphill for Every 2 Watts Downhill)
Mounting Height	Not Less Than 1/10 the Spacing of the Floodlights

Floodlights

Distance From Sideline	No. of Poles	Floodlights		Total Load Kw (10% Over-voltage)
		Units per Pole	Total Units	
30′ or less	10	8	80	139
30′ to 75′	8	12	96	167
75′ or more	6	18	108	188

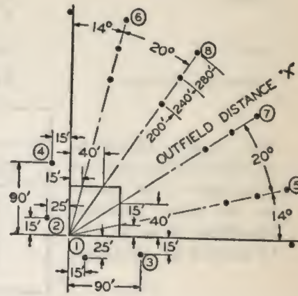
Distance from Sideline	30′ or less	30′ to 60′	60′ to 90′	90′ or More
Beam Spread	65° or more	40° to 65°	25° to 40°	10° to 25°

Lamps *1500-Watt General Service PS-52 Clear Bulb

* For under 200 hours' use per year, operate lamps at 10% overvoltage.
For over 200 hours' use per year, operate lamps at 5% overvoltage.

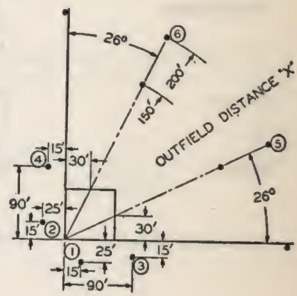
SOFTBALL—CLASS A & B

The distance to the poles in the outfield is determined by the size of the field.



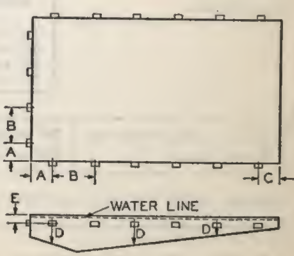
SOFTBALL—AMATEUR—CLASS C

The distance to the poles in the outfield is determined by the size of the field.



SWIMMING POOL—UNDERWATER FLOODLIGHTS

Floodlighting equipment may be located behind water-tight glass plates in the wall of the pool or be of waterproof construction and located in niches in side of pool.



Outfield Distance "X"	200' or less						200' to 240'						240' to 280'					
	Class A			Class B			Class A			Class B			Class A			Class B		
Pole Number	1–2	3–4	5–6 7–8	1–2	3–4	5–6 7–8	1–2	3–4	5–6 7–8	1–2	3–4	5–6 7–8	1–2	3–4	5–6 7–8	1–2	3–4	5–6 7–8
Mounting Height	40'	40'	60'	40'	40'	60'	40'	40'	60'	40'	40'	60'	40'	40'	60'	40'	40'	60'
No. of 1500-Watt Units Per Pole	2	4	3	2	3	2	3	5	5	2	4	3	4	8	6	3	6	4
Total Units	24			18			36			24			48			34		
Kw Load (10% Overvoltage)	42 Kw			31 Kw			63 Kw			42 Kw			84 Kw			59 Kw		

Note: Supplementary corner poles are recommended to carry overhead wires around boundary rather than across playing field.

Lamps *1500-Watt General Service PS-52 Clear Bulb

Floodlights Closed or Open Type, Beam Spread 65° or More

Lamps *1500-Watt General Service PS-52 Clear Bulb

Outfield Distance "X"	150' or Less		150' to 200'	
Pole Number	1–2 3–4	5–6	1–2 3–4	5–6
Mounting Height	40'	40'	40'	40'
No. of 1500-Watt Units per Pole	2	2	2	3
Total Units	12		14	
Kw Load (10% Overvoltage)	21 Kw		24 Kw	

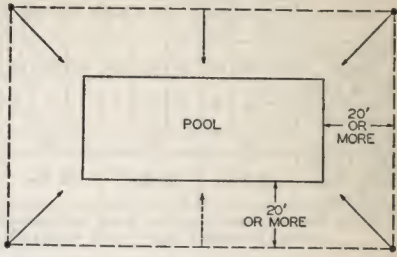
Location of Pool	Recommended Watts Per Sq. Ft.	
	Good Practice	Minimum
Outdoors	3	1.5
Indoors	5	3.0

Size of Lamp	'A' (Ft.)	'B' (Ft. Max.)		'C' (Ft.)	'E' (In.)	
		Where 'D' = 5' +	Where 'D' = 5' —		Min.	Max.
250-Watt, 400-Watt	4	8	10	5	12	15
500-Watt, 1000-Watt, 1500-Watt	6	12	15	7½	18	24

* For under 200 hours' use per year, operate lamps at 10% overvoltage.
For over 200 hours' use per year, operate lamps at 5% overvoltage.

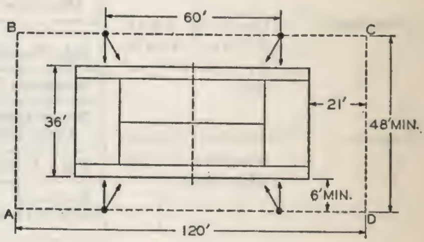
SWIMMING POOL—OUTDOOR—OVERHEAD FLOODLIGHTS

The water as well as the surrounding area should be illuminated.



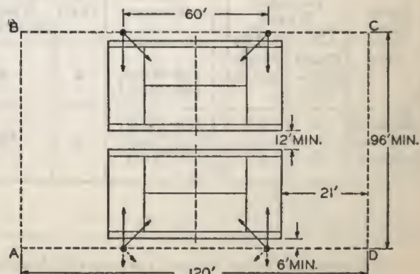
TENNIS—SINGLE COURT

Illumination must be uniform and directed sufficiently high to provide even illumination on the ball during flight.



TENNIS—DOUBLE COURTS OR MULTIPLES OF TWO COURTS

Illumination must be uniform and directed sufficiently high to provide even illumination on the ball during flight.



Floodlights	Closed or Open Type, Beam Spread 50° or More, or Ornamental Standards Spacing Not to Exceed 4 Times Mounting Height
Lamps	500- or 1000-Watt General Service PS Bulb
Load	Watts per Square Foot Including Pool Area Good Practice—1.85 Minimum—0.5
Mounting Height	Conventional Floodlights—25 to 30 Feet Ornamental Standards—18 to 20 Feet

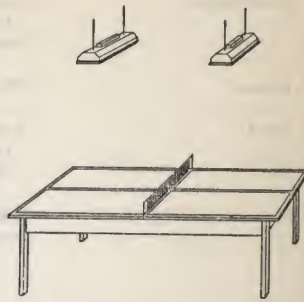
Floodlights	Amateur Play—8, Beam Spread 65° or More Professional Play—12, Beam Spread 65° or More
Lamps	*1000-Watt General Service PS-52 Clear Bulb
Load	Amateur Play—8.6 or 9.3 Kw (5% or 10% Overvoltage) Professional Play—13.9 Kw (at 10% Overvoltage
Mounting Height	30 Feet Above Ground
Poles	Amateur Play—4 Professional Play—8 Professional or Tournament Play Should Have 4 Additional Poles and Floodlights at Points A, B, C and D.

Floodlights	Amateur Play—8, Beam Spread 65° or More Professional Play—12, Beam Spread 65° or More
Lamps	*1500-Watt General Service PS-52 Clear Bulb
Load	Amateur Play—13.0 or 13.9 Kw (5% or 10% Overvoltage) Professional Play—20.9 Kw (10% Overvoltage)
Mounting Height	30 Feet Above Ground
Poles	Amateur Play—4 Professional Play—8 Professional or Tournament Play Should Have 4 Additional Poles and Floodlights at Points A, B, C and D

* For under 200 hours' use per year, operate lamps at 10% overvoltage.
For over 200 hours' use per year, operate lamps at 5% overvoltage.

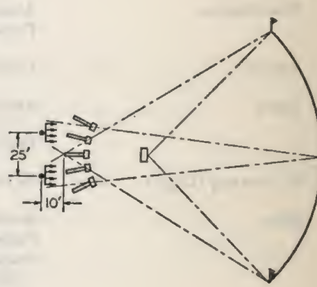
TABLE TENNIS

In professional play three units should be employed, one over the center and one about two feet beyond each end of the table.



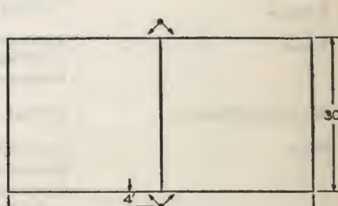
TRAPSHOOTING

Wide beam floodlights are desirable to provide uniform coverage to prevent an apparent variation in bird speed.



VOLLEY BALL—OUTDOOR

This design provides sufficient illumination for recreational play.



Equipment	**2-Lamp RLM Fluorescent Fixtures with Louvers**
Lamps	**40-Watt T-12 White Fluorescent**
Load	**200 Watts**
Mounting Height	**3 to 4 Feet Above Table**

Floodlights	**8, Beam Spread 18° to 35°**
Lamps	***1000-Watt General Service PS-52 Clear Bulb**
Load	**8.6 or 9.3 Kw**
Mounting Height	**20 Feet Above Ground**
Poles	**2**

Floodlights	**4, Beam Spread 65° or More**
Lamps	**500-Watt General Service PS-40 Clear Bulb**
Load	**2 Kw**
Mounting Height	**20 to 25 Feet Above Ground**
Poles	**2**

*** For under 200 hours' use per year, operate lamps at 10% overvoltage.**
For over 200 hours' use per year, operate lamps at 5% overvoltage.

CHAPTER TWELVE

STREET LIGHTING

Good street and highway lighting, often termed "Traffic Safety Lighting," not only promotes safer conditions for drivers but provides greater safety for pedestrians as well. It enhances the community value of a street by its attractive appearance, which is usually reflected in higher property values. Well-lighted streets also act as a deterrent to criminal activity.

In order to achieve truly effective street lighting it is essential that the installation be well planned. Planned street lighting should follow the "Recommended Practice of Street and Highway Lighting" of the Illuminating Engineering Society, and will involve the following considerations:

1. *Traffic classification of the street.*
2. *Determination of the proper lighting intensity for the street classification.*
3. *Selection of luminaires according to the light distribution needed for the street.*
4. *Determination of the mounting height of the luminaire above the road surface and the proper linear spacing between luminaires.*

Each step follows the preceding one in logical order, and the following tables and charts will assist in the accurate planning of an installation.

1. Street classification

A traffic classification should be made of all streets so that the lighting system design will be in keeping with the particular needs of each street or highway. The table shows the vehicular traffic volume classification recommended by the Street Lighting Committee of the Institute of Traffic Engineers.

Classification of Traffic	*Vehicles per Hour
Very Light Traffic	Under 150
Light Traffic	150– 500
Medium Traffic	500–1200
Heavy Traffic	1200–2400
Very Heavy Traffic	2400–4000
Heaviest Traffic	Over 4000

*Maximum night hour in both directions.

It is recommended that all streets be further classified by the volume of pedestrian traffic during the night hours of maximum usage:

***Light or no pedestrian traffic*—as on streets in residential or in most warehouse areas, on express, elevated or depressed roadways or on open highways.**

***Medium pedestrian traffic*—as on secondary business streets and on some industrial streets.**

***Heavy pedestrian traffic*—as on business streets.**

2. Lighting intensity

The proper lighting intensity for each street classification may be determined from the following chart.

RECOMMENDED AVERAGE HORIZONTAL FOOTCANDLES (LUMENS PER SQUARE FOOT) FOR URBAN STREETS				
	Vehicular Traffic Classification			
Pedestrian Traffic	Very Light (Under 150)	Light (150-500)	Medium (500-1200)	Heavy to Heaviest (1200 Up)
Heavy	....	0.8	1.0	1.2
Medium	....	0.6	0.8	1.0
Light or None	0.2	0.4	0.6	0.8

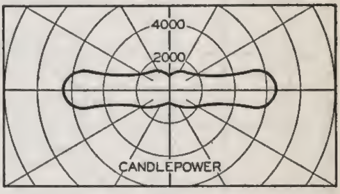
These recommended footcandle levels are the minimum average values on the roadway between curbs. The lowest intensity at any point should not be less than one-fourth of these values. The figures given above are based on favorable pavement reflectance of the order of 10%. When the reflectance is low (3% or less) the illumination recommended should be increased 50%. When the reflectance is unusually high (20% or more) the recommended values may be decreased 25%.

3. Selection of luminaire

Luminaires should be selected according to their pattern of light distribution, so as to conform not only to the light intensity required, but to the physical characteristics of the street to be lighted. Five typical candlepower distribution types showing lateral distribution in the 75° maximum cone are given below:

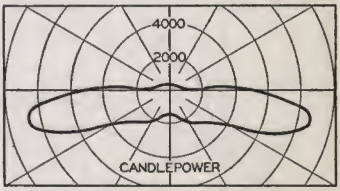
TYPE I LUMINAIRE
Two-Way Distribution

Intended for luminaire mounting approximately over the center of the street. It projects two beams of light in opposite directions along the street, their axis being parallel with the curb line.



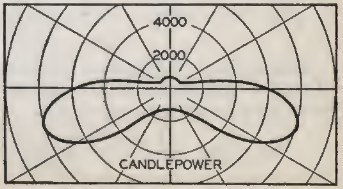
TYPE II LUMINAIRE C-WAY
Narrow Asymmetric Distribution

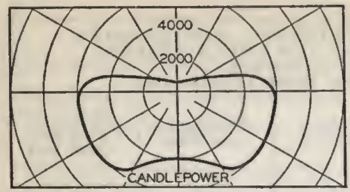
Intended for luminaire mounting at or near the side of the street. It provides narrow distribution, having a lateral width up to approximately 25° in the cone of maximum candlepower.



TYPE III LUMINAIRE B-WAY
Medium Width Asymmetric Distribution

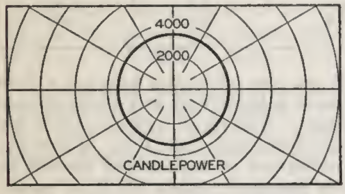
Intended for luminaire mounting at or near the side of the street but having a lateral width up to approximately 45° in the maximum cone. It is intended for wide streets.





TYPE IV LUMINAIRE A-WAY
Wide Asymmetric Distribution

Still wider laterally than type III. The width is about 90° in the cone of maximum candlepower at approximately 75°. Intended for use on widest streets.



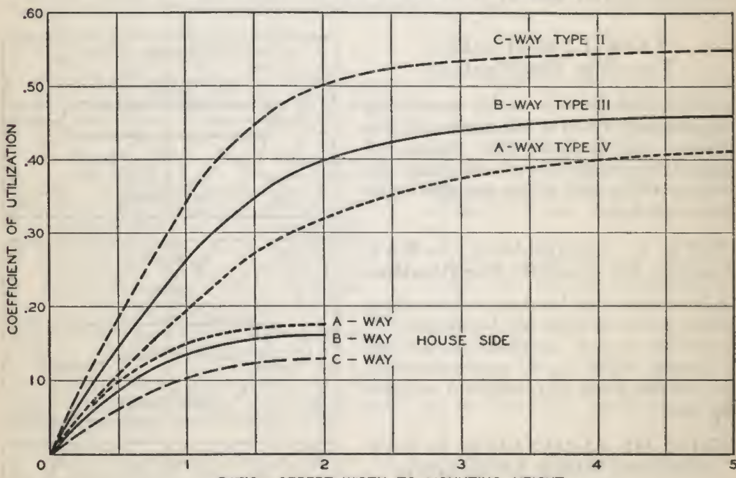
TYPE V LUMINAIRE
Symmetric Distribution

Candlepower in the 75° cone is the same through 360°. It is useful where lighting must be installed in center parkways and to some extent for intersections.

4. Mounting height and spacing of luminaires

Spacing of typical pendant-mounted luminaires may range from as low as three times the mounting height to eight times the mounting height. The table on the next page will assist in determining proper mounting height and luminaire spacing, correlated with street width, lamp size, and specified footcandle values.

UTILIZATION EFFICIENCY CHART



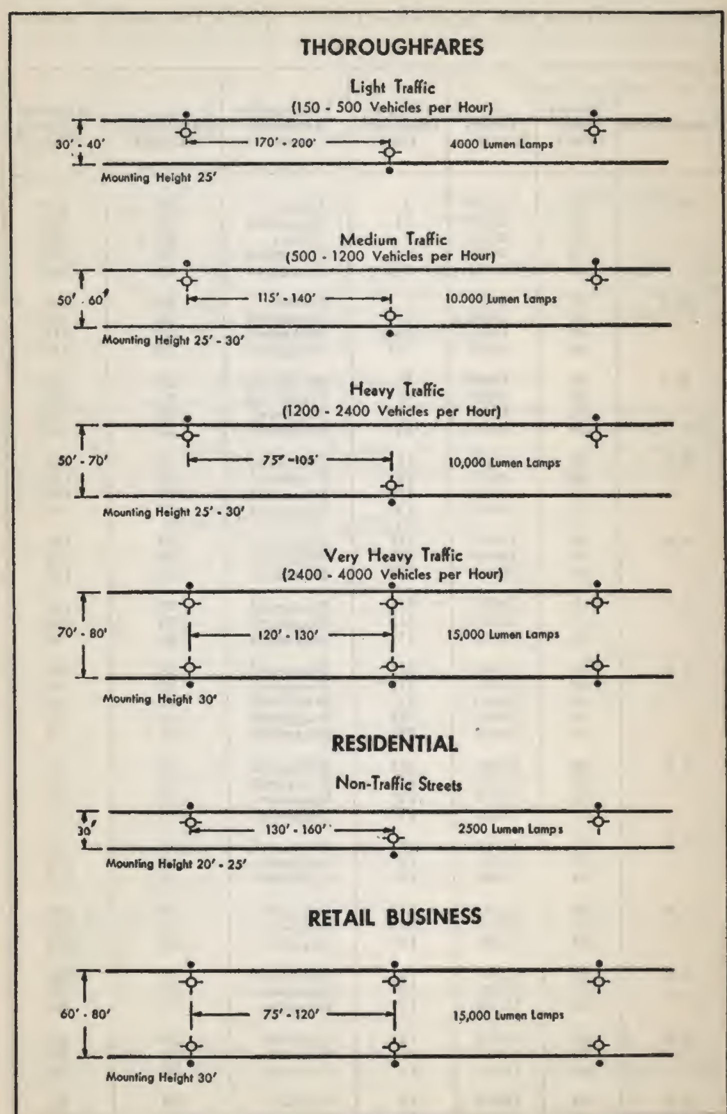
The typical Utilization Efficiency Chart shown above provides a means of checking footcandle intensities when other factors such as lamp lumens, mounting height, street width, and spacing are known.

$$\text{Avg. ft-c} = \frac{\text{Lamp lumens x Coeff. of utilization x Maint. factor}}{\text{Spacing x Street width}}$$

The following table illustrates various combinations of luminaire types, spacings, and lamp sizes required to provide specific footcandle values.

Footcandles	Street Width (Feet)	Lamp Lumens	Type Distribution	Luminaire Arrangement	Mounting Height	Approx. Spacing (Feet)
0.2	30	2500	I	Center	25	170
	30	2500	II	Staggered	20	165
	30	4000	I	Center	25	200
	40	4000	II	Staggered	25	200
	40	4000	III	Staggered	25	200
0.3	30	4000	I	Center	25	180
	30	4000	II	Staggered	25	150
	40	6000	II	Staggered	25	210
	40	6000	III	Staggered	25	210
0.4	40	6000	II	Staggered	25	155
	50	6000	II	Staggered	25	135
	50	6000	III	Staggered	25	140
	50	6000	IV	Staggered	25	110
0.5	40	6000	II	Staggered	25	125
	50	6000	II	Staggered	25	110
	50	6000	III	Staggered	25	110
	50	6000	IV	Staggered	25	90
0.6	50	10000	III	Staggered	30	140
	60	10000	III	Staggered	30	125
	60	10000	IV	Staggered	25	115
0.7	50	10000	III	Staggered	30	120
	60	10000	III	Staggered	30	110
	60	10000	IV	Staggered	25	95
0.8	50	10000	III	Staggered	30	105
	60	10000	III	Staggered	30	95
	60	10000	IV	Staggered	25	85
	70	10000	III	Staggered	30	85
	70	10000	IV	Staggered	25	75
1.0	60	10000	III	Staggered	30	75
	60	10000	IV	Staggered	25	70
	70	10000	IV	Opposite	25	120
	80	10000	IV	Opposite	25	110
1.2	60	15000	IV	Staggered	30	75
	70	15000	IV	Opposite	30	130
	80	15000	IV	Opposite	30	120
1.4	60	15000	IV	Opposite	30	120
	70	15000	IV	Opposite	30	110
	80	15000	IV	Opposite	30	100
1.6	60	15000	IV	Opposite	30	105
	70	15000	IV	Opposite	30	95
	80	15000	IV	Opposite	30	90
1.8	60	15000	IV	Opposite	30	95
	70	15000	IV	Opposite	30	85
	80	15000	IV	Opposite	30	80
2.0	60	15000	IV	Opposite	30	85
	70	15000	IV	Opposite	30	75
	80	15000	IV	Opposite	30	70

TYPICAL STREET LIGHTING LAYOUTS



CHAPTER THIRTEEN

AERODROME AND AIRWAY LIGHTING

The primary purpose of aerodrome and airway lighting is to assist the pilot of an airplane to determine his position relative to the aerodrome after dark, to enable him to make a safe landing, and to permit the plane to be guided into position for efficient handling of passengers and cargo and to be taxied safely to and from the hangar. The amount of light required for these purposes is not always large, but its intensity, direction and color must of necessity conform with rigid standards.

On the following pages are listed the various items of equipment that are generally used for aerodrome and airway lighting. Titles and definitions are those standardized by the Provisional International Civil Aviation Organization. The Civil Aeronautics Administration has recognized the use of these titles in the United States.

The term "aerodrome" includes both airports and airfields, an *airport* being defined as any aerodrome at which facilities available to the public are provided for the shelter, servicing or repair of aircraft, and for receiving or discharging passengers or cargo. An *airfield* is any aerodrome other than an airport. Airports are divided into classes, from I to V, on the basis of effective runway length. The wing loading and power loading of the airplanes to be served determines the class of airport required. The effective landing-strip lengths for the five classes are:

Class I—1800 to 2700 ft.
Class II—2700 to 3700 ft.
Class III—3700 to 4700 ft.
Class IV—4700 to 5700 ft.
Class V—5700 ft. and over

The following table lists the minimum recommended lighting facilities for the five classifications.

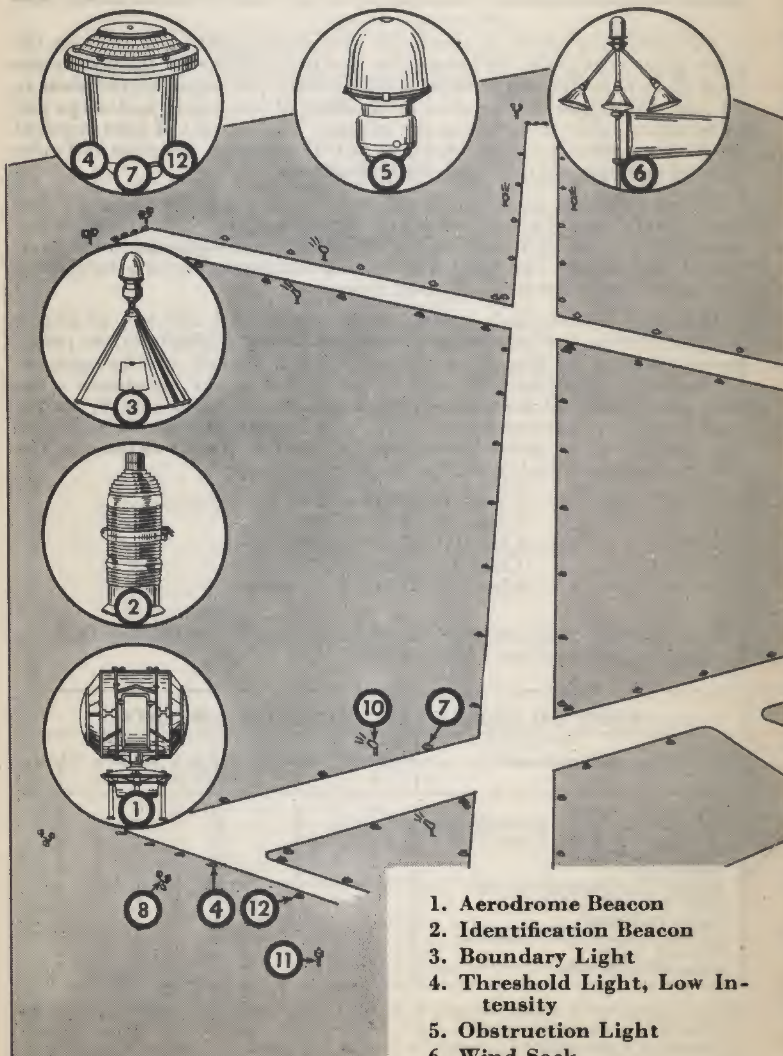
REQUIRED LIGHTING EQUIPMENT FOR AIRPORTS

Type of Equipment	Class I	Class II	Class III	Class IV	Class V
Aerodrome Beacon	X	X	X	X	X
Identification (Code) Beacon ①	X	X	X	X	X
Boundary and Range Lights ②	X	X	X	X	X
Obstruction Lights	X	X	X	X	X
Wind Cone	X	X	X	X	X
Runway and Threshold Lights		X	X	X	X
Wind Tee or Tetrahedron			X	X	X
Apron Floodlights			X	X	X
Ceiling Projector and Clinometer			X	X	X
Taxiway Lights				X	X
Approach Lights ③				X	X

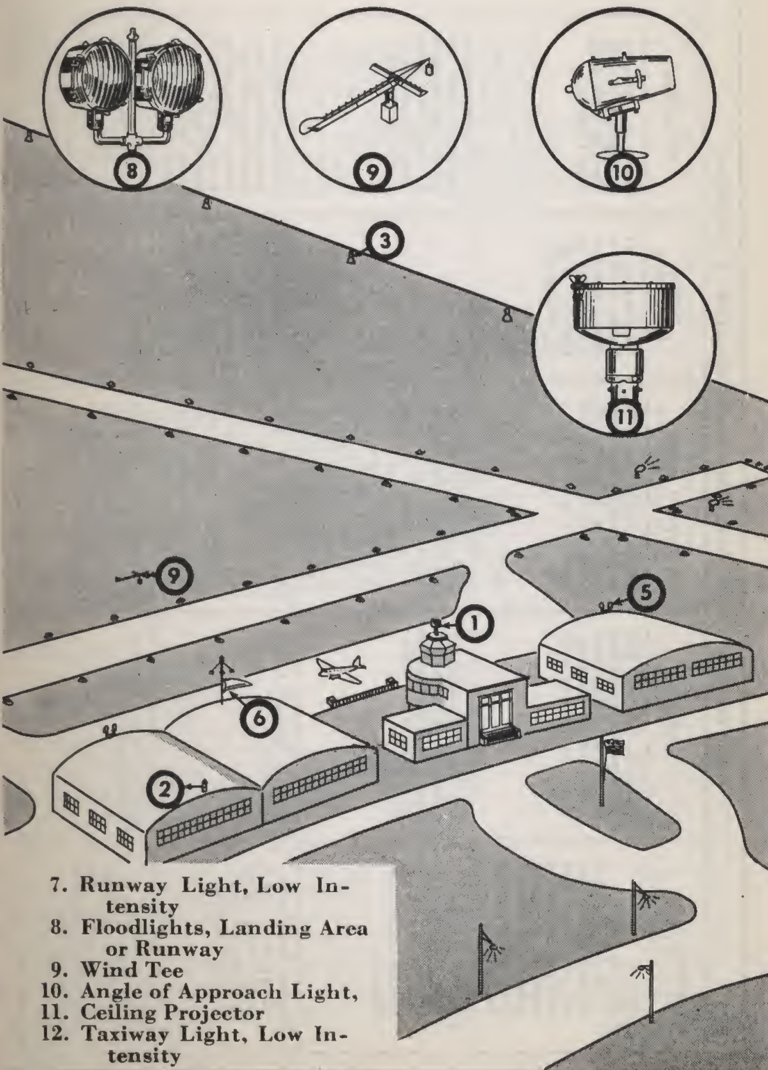
① The Identification (Code) Beacon is required only where one airport must be distinguished from another nearby.

② Boundary Lights should be omitted on runway-type fields.

③ Approach Lights should be installed for each instrument landing runway.



1. Aerodrome Beacon
2. Identification Beacon
3. Boundary Light
4. Threshold Light, Low Intensity
5. Obstruction Light
6. Wind Sock



7. Runway Light, Low Intensity
8. Floodlights, Landing Area or Runway
9. Wind Tee
10. Angle of Approach Light,
11. Ceiling Projector
12. Taxiway Light, Low Intensity

REFERENCE DATA ON AERODROME AND AIRWAY LIGHTING

Equipment and Use	Location	Type of Lamp	Color Indication	Mounting	Spacing
Angle of Approach Light Used to project a characteristic beam of very restricted vertical spread to indicate a desired angle of descent during approach for landing.	Between 500 and 600 feet from approach end of runway, one on each side at edge of paving, or one on left side only.	100-watt 110-volt G-19 bulb medium prefocus base, or 240-watt, 12-volt A-19 bulb medium prefocus base.	Segmental beam yellow at top, green in center, red at bottom, flashing 40 per minute.	Close to ground, on short pipe support on flush Runway Light base.	
Approach Light, High Intensity Used to indicate a desired line of approach to a landing area.	On approach area as extensions of Runway Lights for distance of approximately 2000-3000 feet.	200-watt 6.6-ampere PS-30 bulb mogul prefocus base, 200-watt 6.6-ampere T-14 bulb medium prefocus base, 250-watt 20-ampere T-10 bulb medium prefocus base, or 500-watt 115-volt T-20 bulb medium prefocus base.	Red	On low base at ground, or on poles to establish level grade from runway end or rising curve.	200 feet
Beacon, Aerodrome Rotating type, used to denote location of an airport or airfield.	On or adjacent to an aerodrome.	①500-watt 30 or 115-volt T-20 bulb medium bipost base, 1000-watt 30 or 115-volt T-20 bulb mogul bipost base, or ② 1500-watt 32-volt T-24 bulb mogul bipost base.	Land aerodrome alternate white and green. Water aerodrome alternate white and yellow.	Sufficient height for beam to clear surrounding obstructions. Usually on top of control tower, building, or other structures at least 50 feet high.	
Beacon, Airway Rotating type, used to indicate a particular geographical position on an airway.	On air routes between aerodromes.	①500-watt 30 or 115-volt T-20 bulb medium bipost base, or 1000-watt 30 or 115-volt T-20 bulb mogul bipost base.	White	Towers of sufficient height for beacon to clear surrounding obstructions.	

Beacon, Hazard Rotating type, used to designate an extended or particularly dangerous hazard to air navigation.	Located adjacent to obstructions to air navigation which require special marking because of their extremely hazardous nature.	① 500-watt 30 or 115-volt T-20 bulb medium bipost base, or 1000-watt 30 or 115-volt T-20 bulb mogul bipost base.	Red	Platforms, buildings, towers, etc., sufficient height for beam to clear surrounding obstructions.	
Beacon, Identification Flashing code type, used to identify positively a particular point on surface of earth.	Usually above or immediately adjacent to an Aerodrome Beacon.	500-watt 115-volt PS-40 bulb mogul prefocus base.	Land aerodrome green flashes in Morse code. Water aerodrome yellow flashes in Morse code.	Usually mounted above Aerodrome Beacon, on auxiliary platform where beam will clear all surrounding obstructions.	
Beacon, Landmark Rotating type, used to serve as a particular landmark along an air route.	On air routes.	① 500-watt 30 or 115-volt T-20 bulb medium bipost base, or 1000-watt 30 or 115-volt T-20 bulb mogul bipost base.	Alternate red and white.	Buildings, platforms, towers, etc., sufficient height for beam to clear surrounding obstructions, and to enable the beam to designate the landmark.	
Beacon, Obstruction Marker Flashing type, used in lieu of Obstruction Lights or Hazard Beacon to indicate particularly hazardous obstructions to air navigation.	At *top* of tall or particularly hazardous obstructions.	200-watt 115-volt PS-30 bulb mogul prefocus base, or 500-watt 115-volt PS-40 bulb mogul prefocus base.	Red	Top of narrow obstructions to air navigation, such as radio towers, towers for transmission lines, bridge towers, gas tanks, etc.	
Boundary Light—Airfield Used to outline limits of landing area.	Around boundary of landing area and so circuited that entire landing area is delineated as a unit.	15-watt 115-volt A-15 bulb medium screw base, or 25-watt 115-volt A-19 bulb medium screw base.	White	Normally on boundary cones.	300 feet

① If 500-watt lamp is used with a 24-inch beacon an auxiliary reflector is required.
② For airport use only—can be used only in a special spherical or cylindrical beacon.

REFERENCE DATA ON AERODROME AND AIRWAY LIGHTING

Equipment and Use	Location	Type of Lamp	Color Indication	Mounting	Spacing
Boundary Light—Airport Used to outline limits of landing area.	Around boundary of landing area and so circuited that entire landing area is delineated as a unit.	40-watt 115-volt A-21 bulb medium prefocus base, or 325-lumen 6.6-ampere A-21 bulb medium prefocus base.	White	Normally on boundary cones.	300 feet
Ceiling Projector Used to determine cloud strata height.	At a known distance from observation point, usually 1000 feet.	420-watt 12-volt G-25 bulb mogul prefocus base.	White	Projector mounted to direct beam upward, usually 90 degrees.	
Course Light Used to project a beam of light along course of airway.	At Airway Beacon sites.	500-watt 115-volt T-20 bulb medium bipost base.	Red	Mounted in pairs on opposite sides of Airway Beacon platform below Airway Beacon, so that their beams are projected along course of airway.	
Floodlight, Apron Used to illuminate surface of an apron.	As required, and so positioned as to avoid light being projected into pilots' eyes during landing or taking off of aircraft, and to produce minimum of 0.5 footcandles.	General lighting service lamps.	White	Usually on aerodrome buildings or on ground on flat base or pipe mountings.	
Floodlight, Landing Area or Runway Used for general illumination of runway or landing area.	At end of runway or at edge of landing area.	1500-watt 32-volt T-24 bulb mogul bipost base, or 3000-watt 32-volt T-32 bulb mogul bipost base.	White	Mounted on pipe standards or vaults in banks of two or more units all on one side or on both sides of runway, each bank individually controlled. Mounting height depends upon nature of terrain, 8 feet minimum.	

Obstruction Light—Airfield Used to indicate obstructions or potential hazards to aircraft.	On obstructions: (a) 150 feet or more above landing area and within 2 miles, (b) within approach or take-off areas and extending above a plane of 1:40 inclination, or (c) within transitional areas and extending above a plane of 1:7 inclination.	25-watt 115-volt A-19 bulb medium screw base, 50-watt vibration service 115-volt A-19 bulb medium screw base, or 67-watt traffic signal 115-volt A-21 bulb medium screw base.	Red	At top for heights to 150 feet, with additional light for each 150 feet or fraction thereof, equally spaced. Additional lights will be equally spaced between top light and ground level.	Not over 150 feet horizontal spacing.
Obstruction Light—Airport Used to indicate obstructions or potential hazards to aircraft.	Same as Obstruction Light—Airfield, above.	100-watt 115-volt A-21 bulb medium prefocus base, 111-watt traffic signal 115-volt A-21 bulb medium screw base, or 1020-lumen 6.6-ampere A-21 bulb medium prefocus base.	Red	Same as Obstruction Light—Airfield, above.	Not over 150 feet horizontal spacing.
Range Light Used on an all-way field to indicate a preferred landing path.	Across each end of preferred landing path in boundary light circuits.	100-watt 115-volt A-21 bulb medium prefocus base, or 1020-lumen 6.6-ampere A-21 bulb medium prefocus base.	Green	Normally on cones. Landing paths are coded by using two, three or more lights across each end of same preferred landing path. ①	50 feet apart.
Runway Light, Elevated Used on runways to indicate area available for landing or take-off.	Ten feet out from edge of runway paving, parallel to runway, opposite each other, and so circuited that a single runway may be delineated as a unit.	30 or 45-watt 6.6-ampere T-10 bulb medium prefocus base, or 40-watt 115-volt T-10 bulb medium prefocus base.	White on full length of runway except within 1500 feet of each end of runway, one-half white and one-half yellow	Mounted on ground or on a low base with a breakable joint which will give way if light is accidentally struck by an airplane. ②	200 feet

① The landing path prescribed for use under low wind conditions (less than 5 knots) shall have the greatest number of lights, or in the absence of such prescription the longest landing path shall have the greatest number of lights.

② As new installation, lights shall be located 10 feet out from edge of runway paving opposite each other. As replacements, lights shall be mounted on top of flush Runway Light housings. Maximum extension of 30″ above surface for either installation.

REFERENCE DATA ON AERODROME AND AIRWAY LIGHTING

Equipment and Use	Location	Type of Lamp	Color Indication	Mounting	Spacing
Runway Light, High Intensity Used on all instrument runways to indicate limits of area available for landing and take-off.	Ten feet out from edge of runway parallel to runway, opposite each other, and so circuited that a single runway may be delineated as a unit.	200-watt 6.6-ampere PS-30 bulb mogul prefocus base, 200-watt 6.6-ampere T-14 bulb medium prefocus base, 250-watt 20-ampere T-10 bulb medium prefocus base, or 500-watt 115-volt T-20 bulb medium prefocus base.	White on full length of runway except within 1500 feet of each end of runway, one-half white and one-half yellow.	Mounted on ground or on a low base with a breakable joint which will give way if light is accidentally struck by an airplane. Maximum extension of 30″ above surface.	200 feet
Runway Light, Low Intensity Used on runways to indicate area available for landing and take-off.	Along both edges of runway paving opposite each other, and so circuited that a single runway may be delineated as a unit.	40-watt 115-volt A-21 bulb medium prefocus base, or 325-lumen 6.6-ampere A-21 bulb medium prefocus base.	White on full length of runway except within 1500 feet of each end of runway, one-half white and one-half yellow.	Mounted semi-flush with pavement with heavy prismatic glass and steel cover. Maximum extension of 4″ above surface.	200 feet
Signal Light, Air Traffic Used to signal aircraft where air traffic control is exercised.	Used in control tower.	50-candlepower 6-8 volt S-11 bulb single-contact prefocus base #1063, or 99-watt 110-volt T-8 bulb double-contact prefocus base.	Red, green or white.	Portable or swiveling, usually suspended from ceiling on retractable cable.	
Strip Light, Elevated Used on strips to indicate area available for landing or take-off.	Ten feet out from edge of strip, parallel to strip, opposite each other, and so circuited that a single strip may be delineated as a unit.	30 or 45-watt 6.6-ampere T-10 bulb medium prefocus base, or 40-watt 115-volt T-10 bulb medium prefocus base.	White on full length of strip.	Mounted on ground or on a low base with a breakable joint which will give way if light is accidentally struck by an airplane. ①	200 feet

Taxiway Light, Elevated Used on taxiway to indicate path from terminal building to point of take-off and from point of landing to terminal building.	Along both edges of taxiway. On straight sections, opposite each other. On short sections, curved edges, and intersections, so positioned that path of taxiway is clearly indicated.	30 or 45-watt 6.6-ampere T-10 bulb medium prefocus base, or 40-watt 115-volt T-10 bulb medium prefocus base.	Blue	Mounted on a low base on ground with a breakable joint which will give way if light is accidentally struck by an airplane. ②	200 feet on straight sections.
Taxiway Light, Low Intensity Same as Taxiway Light, Elevated, above.	Same as Taxiway Light, Elevated, above.	40-watt 115-volt A-21 bulb medium prefocus base, or 325-lumen 6.6-ampere A-21 bulb medium prefocus base.	Blue	Mounted semi-flush with pavement with heavy prismatic glass and steel cover. Maximum extension of 4″ above surface.	200 feet on straight sections.
Tetrahedron Used as landing direction indicator where traffic control is exercised. Otherwise swings free to indicate ground wind direction.	On ground near, or on edge of, landing areas, where visible from all points and where wind is not influenced by buildings or natural obstacles.	10-watt 115-volt S-14 bulb medium screw base.	Red on left side, green on right side, top edge and tip.	Mounted on low-friction bearings on vertical shaft to permit free rotation with wind when not controlled from control tower.	
Threshold Light, Elevated Used in conjunction with and in same circuit as Elevated Strip or Runway Light to indicate usable limits of runway or strip.	Across each end of runway or strip symmetrically spaced in two groups, one group on each side of runway or strip, perpendicular to runway or strip, leaving an 80-foot clearance gap at center of runway or strip. ③④	45-watt 6.6-ampere T-10 bulb medium prefocus base, or 100-watt 115-volt T-10 bulb medium prefocus base.	Green	Mounted on ground or on a low base with a breakable joint which will give way if light is accidentally struck by an airplane. Maximum extension of 30″ above surface.	See Location

① Lights shall be located 10 feet out from edge of strip opposite each other. Maximum extension of 30″ above surface.
② As new installation, lights shall be located 10 feet out from edge of taxiway opposite each other. As replacements, lights shall be mounted on top of flush Taxiway Light housings. Maximum extension of 30″ above surface for either installation.
③ When width between Runway Lights is 220 feet or less, six units are required; when width is more than 220 feet, eight units are required.
④ With Strip Lights only six Threshold Lights are necessary.

REFERENCE DATA ON AERODROME AND AIRWAY LIGHTING

Equipment and Use	Location	Type of Lamp	Color Indication	Mounting	Spacing
Threshold Light, High Intensity Used in conjunction with and in same circuit as High Intensity Runway Light to indicate usable limits of runway.	Across each end of runway along a line perpendicular to runway center line, symmetrically spaced in two groups, one group on each side of runway, leaving an 80-foot clearance gap at center of runway.(1)	200-watt 6.6-ampere PS-30 bulb mogul prefocus base, 200-watt 6.6-ampere T-14 bulb medium prefocus base, 250-watt 20-ampere T-10 bulb medium prefocus base, or 500-watt 115-volt T-20 bulb medium prefocus base.	Green	Mounted on ground or on a low base with a breakable joint which will give way if light is accidentally struck by an airplane. Maximum extension of 30″ above surface.	See Location
Threshold Light, Low Intensity Used in conjunction with and in same circuit as Low Intensity Runway Light to indicate usable limits of runway.	Across each end of runway along a line perpendicular to runway center line and at uniformly spaced intervals of 50 feet. On runways less than 150 feet wide only four units should be used.	100-watt 115-volt A-21 bulb medium prefocus base, or 1020-lumen 6.6-ampere A-21 bulb medium prefocus base.	Green	Mounted semi-flush with pavement with heavy prismatic glass and steel cover. Maximum extension of 4″ above surface.	See Location
Wind Sock Used to indicate true wind direction.	On building roof or on ground, where visible from all points and where wind is not influenced by obstacles.	General lighting service lamps as required, usually 100, 150 or 200 watts.	White	Mounted on low-friction bearings attached to pipe standard to permit free rotation with wind and on a hinged pole for ease of relamping.	
Wind Tee Used to indicate true *ground* wind direction.	On ground near landing areas, where visible from all points and where wind is not influenced by obstacles.	25-watt 115-volt A-19 bulb medium screw base.	Green	Mounted on low-friction bearing on vertical shaft to permit free rotation with wind.	Lamps on tee spaced maximum of 1 foot apart.

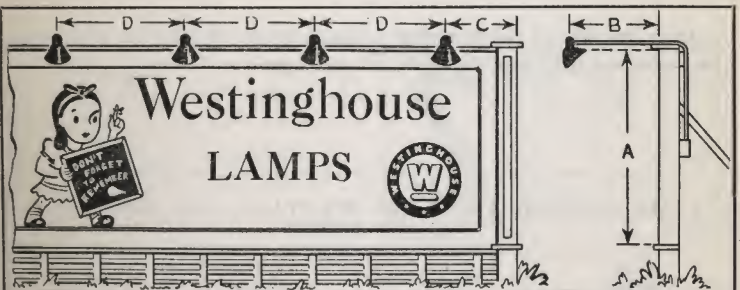
(1) When width between Runway Lights is 220 feet or less, six units are required; when width is more than 220 feet, eight units are required.

CHAPTER FOURTEEN

SIGN LIGHTING

OUTDOOR BULLETINS AND POSTER PANELS

The following diagram and chart present the necessary data for lighting the standard type of outdoor bulletin and poster boards with individual elliptical reflectors. For floodlighting these boards with standard floodlighting equipment the design methods explained in Chapter Eleven should be used.

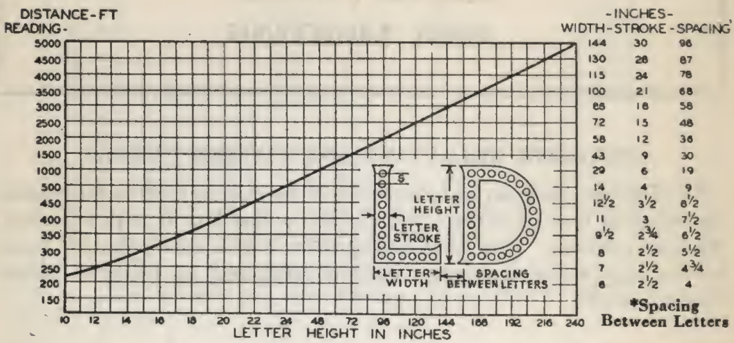


DIMENSIONS FEET				LAMP WATTS		
A	B	C	D	Dark Surroundings	Medium Surroundings	Bright Surroundings
2 to 4	2½	2½	5	50	75	100
5 to 6	3½	3	6	75	100	150
7 to 8	4	3¼	6½	100	150	200
9 to 12	5	4	8	150	200	300
13 to 16	6½	5	10	200	300	500
17 to 21	9	6½	13	300	500	750
22 to 25	12	8½	17	500	750	1000
25 to 30	15	10	20	750	1000	....

EXPOSED-LAMP SIGNS

The proper lamp spacing and lamp wattage in exposed-lamp signs depend upon the height of letter and on the general nature of the surroundings, whether light or dark.

Dimensions for the height, width and stroke of the letters and the spacing between them can be determined from the following table for any reading distance.



After the size of the lettering is determined, refer to the table below for recommended lamp wattages and spacings.

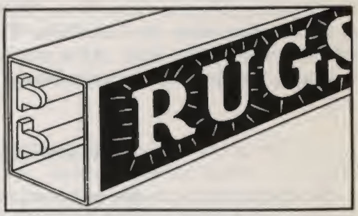
LAMP SPACING AND LAMP WATTAGE FOR EXPOSED-LAMP SIGNS

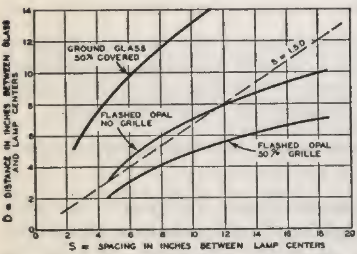
Letter Height	Surroundings	Spacing (Inches)	Wattage
10″–15″	Light Dark	2½ 3	15 10
15″–20″	Light Dark	3 3½	25 10
2′– 3′	Light Dark	3 3½	25 10
3′– 5′	Light Dark	3 4	25 15
5′– 6′	Light Dark	3½ 5	25 15
6′– 8′	Light Dark	4 7	50 15
8′–10′	Light Dark	4 9	50 15
10′–12′	Light Dark	8 12	50 15
12′–16′	Light Dark	10 16	60 15
16′–20′	Light Dark	12 20	100 15

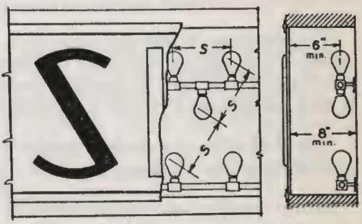
ENCLOSED-LAMP SIGNS

Enclosed-lamp signs are generally of two types: (1) Translucent letters inserted in an opaque background; or (2) opaque letters or painted designs on a glass or plastic background. In each case, the backgrounds are mounted in metal boxes, and illuminated from within by uniformly spaced lamps.

The design of lighting for an enclosed sign follows closely the procedure for designing exterior architectural luminous elements as explained in Chapter Ten. The suggested brightness values given in that chapter apply also to enclosed signs.







LAMP WATTAGE FOR ENCLOSED SIGN LAMPS SPACED 6" ON CENTERS

Greatest Viewing Distance (Feet)	Surroundings	Watts
50– 75	Light Dark	40 10–15
75–100	Light Dark	40 15
100–150	Light Dark	50 15
150–200	Light Dark	60 15
200–300	Light Dark	75 25
300–400	Light Dark	75 25
400–500	Light Dark	75 25

The uniformity of illumination on the glass background depends on three things—the density of the glass, the distance of the lamps behind the glass, and the reflection factor of the interior of the box. The chart shows the spacing of lamps and the distance between the light center of the lamps and the glass for acceptable uniformity of brightness for flashed opal and ground or etched glass. This spacing also applies to continuous rows of fluorescent lamps. As the message on the average sign covers approximately 50 per cent of the background, greater brightness variation is permissible than in Luminous Element Design without decreasing the effectiveness of the sign. As a practical guide, S should equal 1.5D, where S equals the spacing between lamps and D equals the distance to glass.

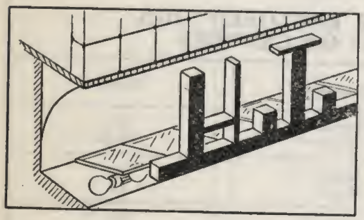
SILHOUETTE SIGNS

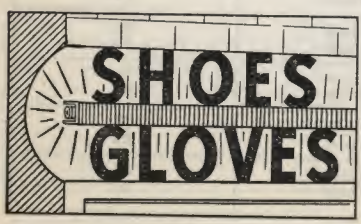
Silhouette signs consist of translucent (often colored) or opaque letters, figures, or designs placed in front of a luminous background. Variable brightness, changing colors, and specular or configurated backgrounds add variety and interest to this type of sign.

The designer must consider that the brightness of the background may affect the apparent width of the strokes of the sign letters or even obscure the finer details of a decorative design due to irradiation effect. This effect is less pronounced if the surrounding illumination is relatively high.

The following table is a guide to the proper size letter for adequate visibility at the distance shown.

Lamp spacing and concealment in silhouette signs are subject to the same general design principles as "Cove Lighting," and reference should be made to Chapter Ten for suggestions on design procedure. It must be remembered that greater freedom in lamp concealment and location is possible for interior signs of this type; exterior signs must have the lamps properly shielded from adverse weather conditions.





LETTER HEIGHT AND VIEWING DISTANCE FOR SILHOUETTE SIGNS

(Background Brightness of 100—250 Footlamberts)

Viewing Distance	Letter Height
200′	5″
400′	8″
600′	12″
800′	16″
1000′	20″

CHAPTER FIFTEEN

THE COST OF LIGHTING

Total cost of light can be computed by assembling all of the factors of both fixed and operating charges which apply to any particular installation. The total thus obtained may serve either as a comparison of the cost of light with other elements of production, or as a comparison of various lighting systems.

In comparing dissimilar lighting systems, such as direct and indirect, it is impossible to evaluate the quality factor from a dollar-and-cents standpoint. Therefore it is desirable to compare the cost of installations on the basis of equal levels of illumination of the same quality. The results thus obtained are a more reliable guide as to the best light source and type of luminaire to employ for a given installation.

There are several other factors which affect or are affected by the lighting installation. The reflection factors of wall and ceiling surfaces are quite important, especially in connection with lighting systems which direct a preponderance of the light to the ceiling. It is difficult, however, to assign any portion of the expense of maintaining these surfaces to lighting cost, since in most cases they are cleaned or repainted to improve the appearance as well as to improve the illumination.

Air-conditioning equipment, while usually purchased independently of the lighting equipment, must have the capacity necessary to remove the heat produced by the light sources. Any increase in its capacity caused by a difference in efficiency of light sources should therefore be included in the cost of lighting. The additional operating cost of this increased capacity should also be considered in the comparison of two lighting systems. Since there are many installations where air conditioning is not a factor, it is not ordinarily included in a cost-analysis form.

Many of the figures used in cost analyses should be secured from someone familiar with the operation and accounting procedure of the business for which the analysis is being prepared. Variation in depreciation methods, borrowing power, cleaning and lamp replacement practices, and power cost, if not correctly estimated, can lead to erroneous results. Some businesses are able to finance projects at much lower rates than others. The number of years in which an investment in lighting equipment is to be written off will depend to a large extent on company accounting procedure. The cost of luminaire cleaning and lamp replacement will vary with the kind of labor used and whether or not the lamps are replaced on a group basis. It is well to take advantage of the experience of the customer in arriving at the estimates for these items. In all cases the figures used for each item should be those that apply to the specific conditions encountered in the particular installation.

TYPICAL COST-ANALYSIS FORM

FIXED CHARGES	Lighting Method #1	Lighting Method #2
1. Number of luminaires	....	....
2. Approximate cost of each luminaire Net price less lamps	....	....
3. Approximate cost of additional accessories	....	....
4. Estimated cost of wiring per luminaire This includes all wiring materials such as conduit, wire and fittings, and the labor necessary to install the wiring and fixtures. This figure will vary greatly, depending on the number and type of units, accessibility, type of construction, etc. Panels, feeders and transformers, if necessary, should be proportioned in this cost.	....	....
5. Complete installation cost per luminaire Sum of Lines 2, 3 and 4	....	....
6. Total installation cost Line 1 x Line 5		
7. Depreciation per year (___% of Line 6) The proportion of the initial expenditure to be written off each year is dependent upon the nature of the business. In considering industrial plants, where fixture styles change infrequently, 10% or less may be used. The motifs of commercial establishments change frequently, and the depreciation factor may approach 20%. The purchaser should be consulted.	....	....
8. Interest, taxes and insurance (___% of Line 6) The interest rate will vary with the company's borrowing power, and existing financial market conditions. Taxes and insurance are a function of property valuation, location and type of business. The sum may vary from 7 to 10% per year.	....	....
9. Total Annual Fixed Charges Sum of Lines 7 and 8	....	....
OPERATING CHARGES		
Lamps—		
10. Total number of lamps	....	....
11. Lamp life in hours	....	....
12. Lamp cost—net	....	....
13. Labor cost to renew each lamp	....	....
14. Total cost to renew one lamp Sum of Lines 12 and 13	....	....

TYPICAL COST-ANALYSIS FORM—(Cont.)

OPERATING CHARGES (Cont.)	Lighting Method #1	Lighting Method #2
15. Renewals per year $\frac{\text{Line 10 x Operating hours}}{\text{Lamp Life}}$	....	....
16. Annual cost of lamp renewals Line 14 x Line 15	....	....
Cleaning Cost—	....	....
17. Cleaning frequency per year	....	....
18. Cost of cleaning per luminaire	....	....
19. Annual cost of cleaning Line 1 x Line 17 x Line 18	....	....
20. Minor repairs and replacements Glassware, ballasts, starters, sockets, etc., per year	....	....
21. Total maintenance cost per year Sum of Lines 19 and 20	....	....
Power Cost—		
22. Watts per luminaire (including auxiliaries)	....	....
23. Annual Kwh used $\frac{\text{Line 22 x Line 1 x Operating hours}}{1000}$	....	....
24. Annual power cost (Line 23 x ___¢ Power rate)	....	....
25. **Total Annual Operating Charges** Sum of Lines 16, 21 and 24		
26. TOTAL ANNUAL COST OF LIGHTING* Sum of Lines 9 and 25		
27. Cost per sq. ft.		
28. Cost per footcandle		

* Where light sources which vary markedly in their heat production are being considered in connection with air-conditioned areas, the annual depreciation and operating charges or the additional air-conditioning capacity required should be added to this cost.

CONVERSION EQUIVALENTS

Distance

1 inch = 2.54 centimeters

1 kilometer = 0.6214 miles

Circumference of circle = πD ($\pi = 3.1416$, D = diameter)

Circumference = 2π radians

1 radian = the arc whose length is equal to the radius = 57.3° of angle

Area

1 sq inch = 6.452 sq centimeters

Area of sphere = πD^2

Area of triangle = ½ altitude x base

Area of circle = $\frac{\pi D^2}{4} = 0.7854\ D^2$

Area of trapezoid = ½ (sum of parallel sides) x altitude

Volume

1 cubic inch = 16.39 cubic cm = 0.01639 liters

1 cubic yard = 0.7645 cubic meters

1 cubic meter = 35.32 cubic ft

Volume of sphere = $\frac{\pi D^3}{6} = 0.5236\ D^3$

Volume of cone = area of base x 1/3 altitude = $1.0472\ r^2h$

Energy—Power

1 watt = 0.00134 horsepower

1 kilowatthour = 3414 Btu

1 joule = 1 watt-second = 0.738 ft-lb

1 horsepower-hour = 2544 Btu

1 ft-lb per second = 0.001818 horsepower

1 horsepower = 746 watts = 33,000 ft-lb per min = 550 ft-lb per second

Heat—Temperature

1 Btu = 778 ft-lb = 0.00039 hp-hr

1 Btu per min = 17.6 watts

1 Btu = 252 calories (gram)

1 calorie = 0.003968 Btu

1 Btu = heat required to raise 1 pound water 1 degree F

1 calorie = heat required to raise 1 gram water 1 degree C

Degrees Centigrade = 5/9 (°F − 32)

Degrees Fahrenheit = 9/5(°C) + 32

Degrees Kelvin = °C + 273

Light

1 lux = 1 lumen per square meter = 0.0929 footcandles

1 candle per sq in. = 452 footlamberts

1 lambert = 929 footlamberts = 2.054 candles per sq in.

1 stilb = 1 candle per sq cm = 6.452 candles per sq in.

Mean spherical candlepower = $\frac{\text{lumens}}{12.57}$

Miscellaneous

1 in. mercury = 0.491 lb per sq in.

1 atmosphere = 14.69 lb per sq in. = 29.92 in. Hg = 33.9 ft water

1 year = 8760 hours (365 days)

Formula for parabola: $y^2 = 4ax$

Formula for ellipse: $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

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